JOURNAL OF

METALS

JUNE 1956

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Industrial Gas Mains 6" to 120"

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Bailey GOGGLE VALVES

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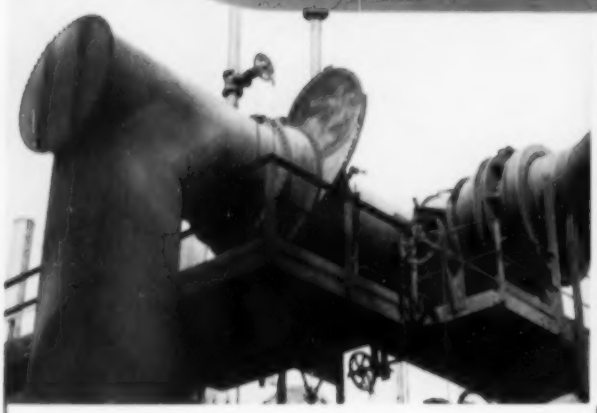

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COVER

Artist Harry Brocke chooses a portrait of Henry Bessemer to commemorate the 100th anniversary of the use of the Bessemer steelmaking process. The story of this first century is recounted on page 742 and highlights of some of the celebrations, including the honoring of the oldest living steel blower, are shown on page 741.

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(Continued on page 724)

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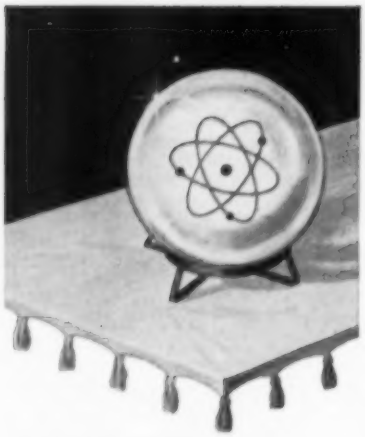

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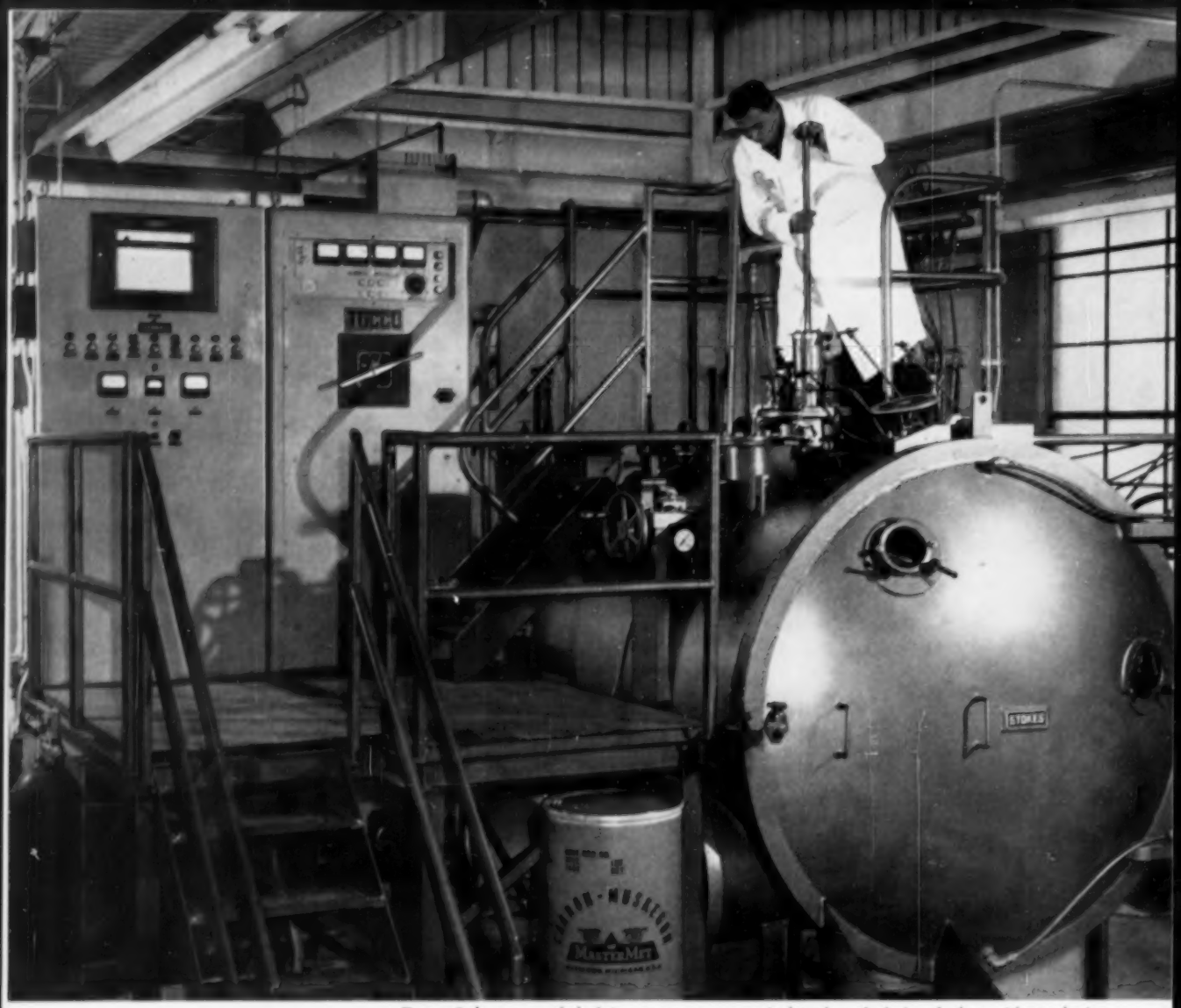

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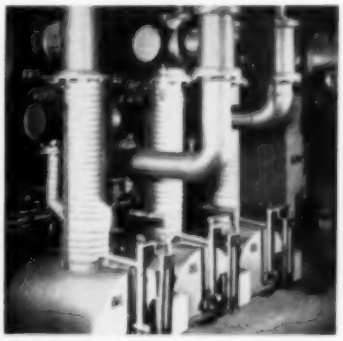

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STOKES

Personnel Service

(Continued from page 718)

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Chemical Engineering, Volume II: Unit Operations, by J. M. Coulson and J. F. Richardson, *McGraw-Hill Book Co. Inc.*, $9.00, 585 pp., 1955.—Applying the basic principles of dynamics, heat and mass transfer discussed in Volume I, this volume deals with such operations as flow of fluids through granular beds and packed columns, filtration, gas cleaning, leaching, distillation, crystallization, and drying. Although basic principles are stressed, the treatment is sufficiently practical to be of value to engineers in industry.

Titanium, Metallurgy of the Rarer Metals, No. 4, by A. D. McQuillan and M. K. McQuillan, *Academic Press Inc.*, or *Butterworths Scientific Publications*, $10, 466 pp., 1956.—A comprehensive survey of the basic properties of titanium metal and its alloys is presented, rather than details of its industrial technology. Since titanium technology is unusually dependent on the fundamental nature of the metal, the principles involved in the production and processing on an industrial scale have been included. The chapters have been arranged to give a unified picture of the metal and to facilitate continuous reading.

An Outline of Atomic Physics, by Oswald H. Blackwood and others, *John Wiley & Sons Inc.*, $7.50, 501 pp., 3rd edit., 1955.—In this book written for readers with a knowledge of elementary physics, structures of atoms and molecules and the nature of radiation are discussed. Established subjects such as the periodic system and the Bohr model of the atom, as well as newer topics—nuclear fission and cosmic rays—are also covered.

Birth and Development of the Geological Sciences, by Frank Dawson Adams, republished by Dover Publications Inc., New York, $1.95, 511 pp., illustrated, 1955.—Including material drawn from over 500 writers such as Aristotle, Becher, and Humboldt, the author shows the chief difference between scientists of the modern era and those of the past—the superstitions once held by scientists. The book is a collection of early metallurgical lore.

Specifications and Tests for Electrodeposited Metallic Coatings, *ASTM*, $1.85, $1.40 for ASTM members, 96 pp., 1955.—Coatings of zinc, cadmium, Ni-Cr, and lead on steel; Ni-Cr on copper and zinc, and chromate finishes on zinc coatings are included in the specifications given. Several recommended practices for chromium plating on steels and the preparation of various metals for plating are discussed. Local thickness and other test methods are also included.

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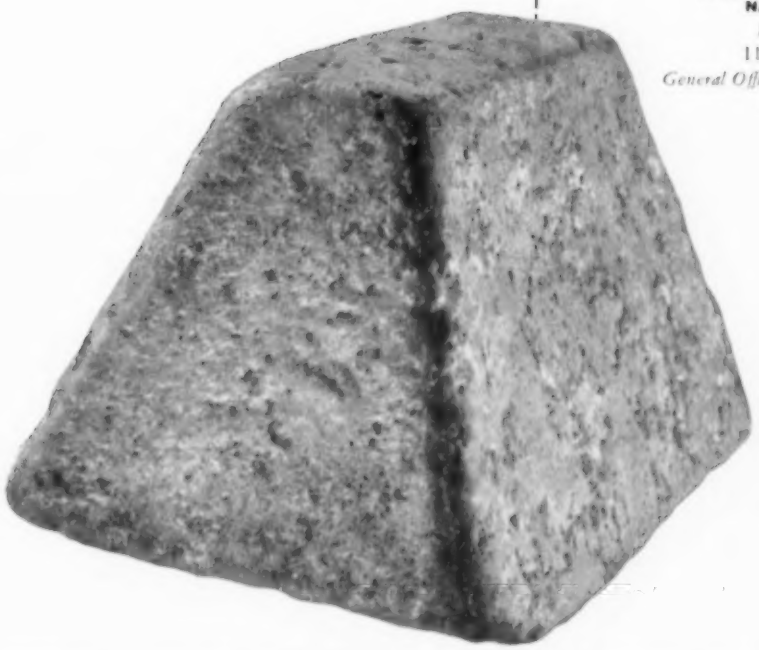

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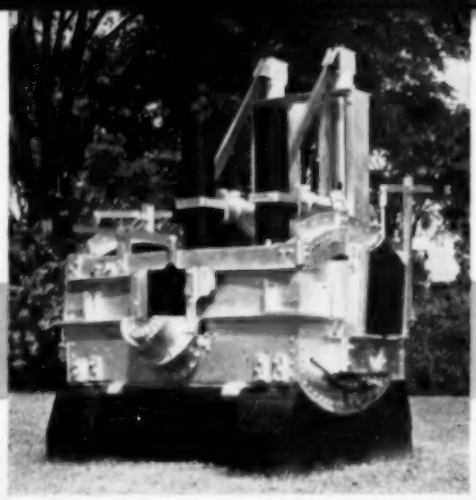

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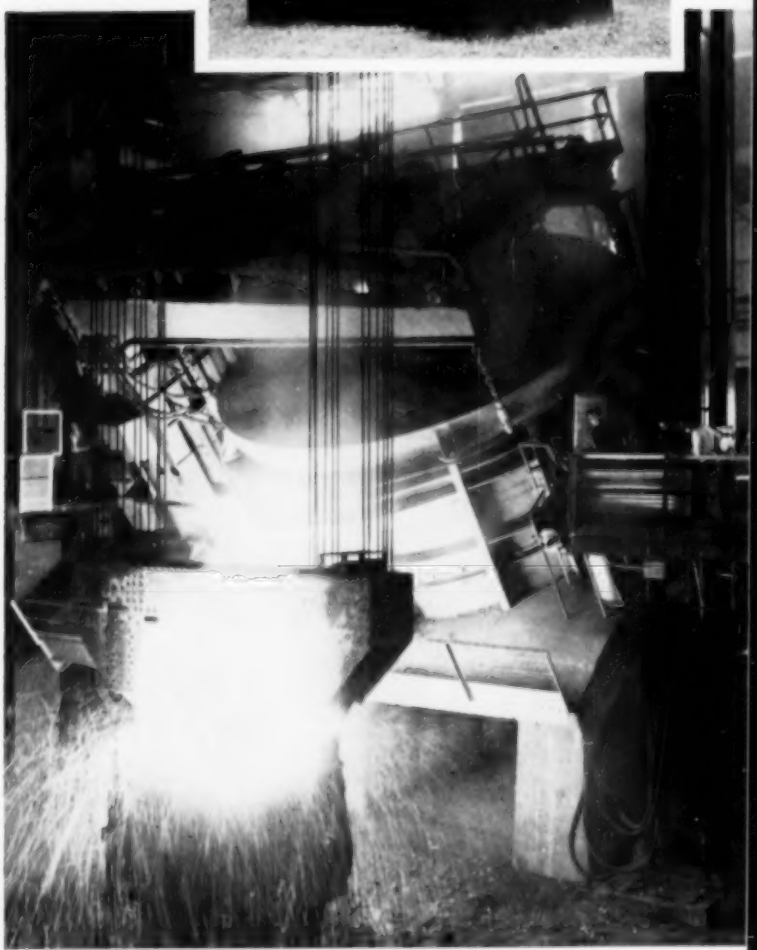

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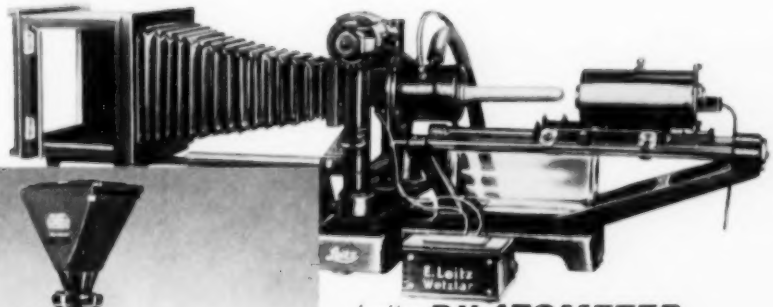

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EJC Reports on:

Professional Standards and Employment Conditions

UNLIKE the members of most learned professions, the engineer usually is an employee rather than a private practitioner. Surveys indicate that about eighty per cent of professional engineers are in the employee classification, and this situation sometimes creates special problems which are not inherent in the other professions. One such problem is how specifically to create and maintain an employment atmosphere consistent with high professional standards.

Certain conditions of employment have had a profound influence on engineers and, among other factors have caused a number of professional employee groups to turn to collective bargaining. There is a need, therefore, for the engineering profession to state clearly the employment conditions that engineers expect as professional men. Employers should align their policies with respect to the engagement of professional engineering personnel to meet these expectations. Mutual understanding between employers of engineers and the engineering profession is essential to the establishment of an environment which will encourage the individual engineer to achieve full professional stature.

A special committee of Engineers Joint Council was charged with a study of this employment problem and the preparation for Engineers Joint Council of "a means of education of and vertical communication to the membership of the constituent societies (including students) concerning conditions surrounding unionization of professional personnel."

Another assignment of the special committee was the preparation of information for employers of engineers concerning employment practices, educational opportunities, and general measures for professional development that influence the attitudes of engineers toward a true professional outlook.

This study treats but one of many problems confronting the profession. Engineers Joint Council will continue its study of the problems related to the employed engineer.

THE PRESENT SITUATION

The expansion of engineering from its beginning in military and civil engineering a century ago to a multiplicity of disciplines today has created a host of problems. Of major concern to the engineer is his relationship as a professional man with his employer. This relationship is influenced largely by employment conditions including salaries, training programs, security policies, levels of responsibility, job classifications, and identification with management.

Because the needs, responsibilities, and contributions of professional employees have not been recognized adequately in some instances there has been a movement toward the unionization of engineering personnel. This has had an adverse affect on the professional concepts of many engineers, for a professional man must rely first on his own personal competence and integrity for recognition. In addition, confidential relationships which should exist between employers and professional engineers have been jeopardized.

The fact that there has been a trend toward collective bargaining by engineers, in spite of widespread reluctance to participate in such action, indicates the existence of unsatisfactory conditions. The engineering profession and management have a great stake in the solution of the problem and the latter must accept its share of the responsibility for alleviating unfavorable employment conditions.

THE CAUSES OF THIS CONDITION

Reasons which have fostered collective bargaining among engineers have been studied and may be grouped as follows:

Professional Treatment

1. A feeling among engineers that they were not identified with management, whether they were employees in industry, private engineering firms, or public service.
2. Inadequate channels of communication between top management and nonsupervisory engineers.
3. Inadequate recognition of the engineer as a professional employee.
4. Assignment of engineers to subprofessional work.
5. Undue retention of engineers in specialized and narrowly compartmentalized assignments.
6. Lack of appropriate means for resolving individual problems.

Personal Treatment

1. Inadequate recognition and treatment of the engineer as an individual.
2. Lack of broad position classifications and appropriate titles by which the engineer could measure his progress.
3. Inadequate or nonexistent plans for training and job rotation.
4. Inadequate understanding of promotional policies and belief that progress and promotions were not commensurate with ability and performance.
5. Feeling of insecurity of employment.
6. Management's human relations knowledge and skills have not kept pace with the expanded utilization of engineers.

Financial Treatment

1. Engineering salaries not commensurate with fundamental contribution.
2. Too small a differential between the pay of engineers and members of the skilled trades.
3. Salaries of experienced engineers not sufficiently increased, in comparison with present starting salaries.
4. Wide variation in salaries paid to engineers doing comparable work in different organizations.
5. Dissatisfaction with merit review systems and inadequate understanding of salary administration.

Faced with these conditions, some engineers have resorted to unionization in the belief that corrective action could be effected only by pressures on management through collective bargaining. Even though they may have realized that professionalism requires freedom of action, these engineers appear to have been willing to submerge this principle in their attempt to get more pay and better working conditions through union activity.

SUMMARY OF HISTORICAL BACKGROUND

The accelerated development of mass-production techniques in this century stimulated a rapid rise in labor union activities. Labor and management faced common problems of increasing complexity. In 1935 the United States Congress enacted the National Labor Relations Act, better known as the Wagner Act, which guaranteed to employees the right to organize and to bargain collectively and protected labor unions against specified unfair labor practices on the part of management. At that time there was little realization on the part of the professions of the potential impact of the Wagner Act on professional employees. However, the established labor unions soon took advantage of the situation and it was not long until many professional employees found themselves included, against their individual desires, in heterogeneous bargaining groups.

Legally, it was possible to form bargaining groups composed solely of professional employees. Practically, it was difficult to do so. Wherever a heterogeneous bargaining unit existed, it was next to impossible for professional employees to segregate themselves since the Wagner Act made no distinction between them and nonprofessional workers.

Some engineering societies, particularly the American Society of Civil Engineers, undertook to chart a course of action designed to assist professional employees against inclusion in heterogeneous groups. At first, the effort met with but minor success. Later, Engineers Joint Council determined to present its views to Congress with the hope that the Wagner Act might be amended to provide recognition of the status of professional employees and to enable them to act effectively on their own behalf. Pertinent clauses are included in the Labor Management Act enacted by Congress in 1947—better known as the Taft-Hartley Act.

Of interest to the engineering profession, this law specifically provides under Section 9 (b):

> "The Board shall decide in each case whether, in order to assure to employees the fullest freedom in exercising the rights guaranteed by this Act, the unit appropriate for the purposes of collective bargaining shall be the employer unit, craft unit, plant unit, or subdivision thereof; PROVIDED that the Board shall not (1) decide that any unit is appropriate for such purposes if such unit includes both professional employees and employees who are not professional employees unless a majority of such professional employees vote for inclusion in such unit . . ."
>
> The term *professional employee* as included in the Act reads
>
> "(a) any employee engaged in work (i) predominantly intellectual and varied in character as opposed to routine mental, manual, mechanical, or physical work; (ii) involving the consistent exercise of discretion and judgment in its performance; (iii) of such a character that the output produced or the result accomplished cannot be standardized in relation to a given period of time; (iv) requiring knowledge of an advanced type in a field of science or learning customarily acquired by a prolonged course of specialized intellectual instruction and study in an institution of higher learning or a hospital, as distinguished from a general academic education or from an apprenticeship or from training in the performance of routine mental, manual, or physical processes; or, (b) any employee who has (i) completed the courses of specialized intellectual instruction and study described in clause (iv) of paragraph (a), and (ii) is performing related work under the supervision of a professional person to qualify himself to become a professional employee as defined in paragraph (a)."

Under the Taft-Hartley Act a group of professional employees in any place of employment may decide by majority vote of their own numbers whether they want to form a unit of their own for collective bargaining purposes, to join with some other bargaining group, or to refrain from collective bargaining entirely.

It was hoped that the amended act would provide a satisfactory solution to the inclusion of engineers in heterogeneous unions. Professional employees could disassociate themselves from heterogeneous groups. It was not expected that employees of professional status ever would desire anything like a nation-wide bargaining union. It was hoped that labor unions would respect the statutory rights of professional employees.

Those hopes today lack much of full realization.

A number of bargaining groups of professional employees have come into existence. Some appear to have functioned constructively; the same hardly can be said of others. Already there is a nation-wide union, self-designated as an engineering union, which aspires to power. Although some professional employees have been able to disassociate themselves from heterogeneous groups, craft unions, particularly in the construction industry, are forcing more and more engineers into their ranks by bringing economic pressure upon employees, thus avoiding the election machinery of the Taft-Hartley Act. Clearly, many members of the engineering profession and employers of engineers are not doing enough to ensure enforcement of the letter and the spirit of the law.

The recent merging of the American Federation of Labor (AFL) and the Congress of Industrial Organizations (CIO) brings into being a large and powerful labor organization among whose objectives are increased efforts toward unionization of office employees and technical personnel. That effort will have direct impact on professional engineers.

To obtain reliable statistics regarding the current status and thinking of a cross-section of the engineering profession, four constituent members of EJC, namely, ASCE, ASME, AIEE, and SNAME, polled 117,917 of their members on specific questions concerning collective bargaining. Of those polled 66,938 or 57%, responded.

Returns showed that 48,082, or 72%, of the 66,938 respondents opposed collective bargaining for professional engineers, and that 44,168, or 66%, felt that collective bargaining is incompatible with professional status.

Further, the 66,938 responses showed that less than 4% were actually members of established collective bargaining groups; 27% reported as not being opposed to collective bargaining; 20% reported that they believed collective bargaining would be advantageous to them; and finally, less than 1% of the membership of three member societies (the fourth did not ask the question), would prefer to be represented by a craft labor union.

These results present a challenge to the engineering profession and to engineering management. The thinking of the remaining 43% of the 117,917 members polled, who did not respond to the questionnaire, is still unknown, but, assuming that the sample was representative, there would then be 30,300 members who are not opposed to collective bargaining for professional engineers.

These results emphasize the situation confronting the profession in spite of the protective clauses in the Taft-Hartley Act.

Statement of the Problem and Suggested Solutions

A summary of the above might lead to two basic reasons for the present situation:

1. Engineers have not always realized and understood the professional characteristics of their roles.
2. Management has not always realized and accepted its obligations to engineers.

If these are the causes, the problem then may be stated as how to get the engineer to appreciate the professional characteristics of his position and how to get management to realize and accept its obligations to its engineers.

Immediately certain solutions present themselves, and these may be listed under five main headings:

1. Point out to the engineer and reemphasize to him that engineering is a profession and that he therefore has certain definite responsibilities.
2. Point out to management, through all feasible ways, that it has responsibilities to the engineering profession.
3. Point out to professional societies the part which they should play in the advancement of their profession.
4. Point out to engineering educators their responsibilities for developing professional concepts in their students.
5. Point out to society the contribution of the engineer to its general welfare.

The purpose of the rest of this report will be to bring to the attention of all concerned their respective responsibilities. It is hoped that sufficient distribution and publicity will be given to it to stimulate a realization on the part of the public that engineering is a profession with high ideals and one that has made preeminent contributions to our modern civilization and high standard of living.

ENGINEERING—A PROFESSION

Engineering is the art and science by which the properties of matter and energy are made useful to man in structures, machines, and products. Accomplishment of these ends requires not only scientific training, but also creative imagination, judgment, and an appreciation of the economics involved. The work of the engineer is predominantly intellectual and varied.

(Continued on page 730)

The dictionary defines engineering as a mental activity rather than a manual skill. The engineer must exercise discretion and judgment, he must wish to serve, and his relationship with management must be one of confidence; in fact he is part of management. The engineer is charged with the protection of the public health and the public safety. The builder of a bridge, an airplane, a water supply, a dynamo, a kitchen range, an automobile, or a chemical plant must be concerned with its safe operation. Responsibility rests upon his shoulders; if he does not accept that responsibility, he is not professional.

Professions require knowledge and skills on a high plane and all require that the practitioner work in a relation of confidence. In the ministry, medicine, and law this relationship is usually on an intimate personal basis, but in engineering it usually is more general and, indeed, involves obligation to the public at large as well as to the employer or client. The engineer's code of ethics requires that "he will have due regard for the safety of life and health of the public and employees who may be affected by the work for which he is responsible" and that "he will act in professional matters for each client or employer as a faithful agent or trustee."

Since clients and employers usually do not have the technical knowledge necessary to judge technical work, the engineer is bound to place their protection above his personal convenience or his immediate personal gain. A fundamental principle of professional responsibility is trusteeship. This is also a fundamental principle of management. To the employed engineer this means that the professional attitude involves a "management-oriented" point of view.

Engineering operations today are varied and extensive. Men at all levels of training and competence are required to carry out vast engineering enterprises. The work of the draftsman, the layout man, the toolmaker, the plant operator is indispensable, but does not require the imagination, the educational background, nor the judgment of the engineer who conceives and executes the broader aspects of the projects.

The work of a truly professional engineer is so far from a routine, established pattern that only he can provide the initiative, the discretion, and judgment to achieve the successful accomplishment of his particular tasks. Because he alone knows with what comprehension, ability, and likelihood of success he approaches his assignment, the professional must accept individual responsibility or else advise his client or employer that other help is needed.

Professional attitude involves the following five basic concepts:

1. A social consciousness, a desire to contribute *to* rather than simply to benefit *from* civilization; a resolve to place the public welfare above other considerations.
2. The acquisition of special skills on a high intellectual plane, generally evaluated by means of self-imposed standards of excellence.
3. A sense of trusteeship—personal responsibility to protect the client's or employer's interest.
4. Individual initiative and acceptance of individual responsibility, both of the highest order.
5. A right to expect and to receive adequate financial recognition.

Prestige, however, is something that must be won. It cannot be bought or automatically accorded through affiliation with an organization. It is something that one can *command* but never *demand*. In the final analysis, an engineer achieves professional standing only to the extent that he accepts his responsibility to himself, to his client or employer, and to society.

Attainment of a degree in engineering from an institution of recognized standing implies that the graduate has mastered a certain curriculum and that he has the ability to understand, to assimilate, and to apply the knowledge that qualifies him to become a member of the engineering profession.

Although social consciousness is not necessarily a corollary to superior mental competence, most people who are endowed with such competence do have a sense of responsibility to the social order of which they are a part. They have learned to look on life an an opportunity to contribute to the civilization that fostered them and thus to better the lot of those who follow. To the engineer who feels that life provides opportunity for constructive contribution to society, collective bargaining with its attendant potentiality for creating conflicting obligations is not acceptable.

Employee's Responsibilities in the Profession

"As an engineer, I will participate in none but honest enterprise. To him that has engaged my services as employer or client, I will give the utmost of performance and fidelity." (*Faith of the Engineer.*)

The engineering employee is bound by the same ethical and moral principles that apply to a member of any other learned profession. The responsibilities of an engineering employee are many. He is obliged to perform the professional assignments entrusted to him to the best of his knowledge and ability. He should give needed professional counsel in his special field and render loyal service. He should respect the economic problems of his employer. He should be thorough, expeditious, original, and accurate in the execution of his duties and assignments. He should have a rational attitude toward his work and fulfill each task with a minimum of supervision. At all times he should strive to improve the quality and increase the quantity of his output.

Education is important to the engineer and he should foster its continuance for those who are subordinate to him. He should strive to recognize and to utilize the diverse capacities of all fellow employees. He should strive for good planning and clear, concise reports. He should be friendly and maintain good appearance. He should develop the ability to be a good listener as well as the ability to express his thoughts effectively.

It is axiomatic that just as management has responsibility to employees, so do employees have responsibilities to management. The engineer employee should realize that he is not just another hired hand. He should know that to achieve full professional stature he must develop himself to rise above the technician or engineering-assistant. He must have genuine desire to expand his capacity, to extend his knowledge, and to improve his proficiency.

Any employee who is unwilling to assume responsibilities beyond those accompanying his present job has little right to be critical about lack of advancement. If he feels that he is not getting earned recognition, it well may be that critical self-appraisal is in order. One cannot just wish himself up the ladder or depend on someone else to push or pull him along the way to success. The fact that a man has acquired a bachelor's degree in engineering does not, of itself, entitle him to any lasting professional recognition. It remains for each individual to prove by his own ability, integrity, and conscientious application to duty that he deserves recognition.

Management's Responsibilities

Surveys show that more than forty per cent of management were trained as engineers. It seems illogical, therefore, that often there is inadequate communication between management and engineers with consequent lack of understanding on the part of management of the reasons for dissatisfaction among professional employees.

Management must recognize the inherent professional character of engineering work. It should be a policy of management to use its professional employees to the maximum of their capabilities. Except during the training period the engineer should not be assigned to

(Continued on page 732)

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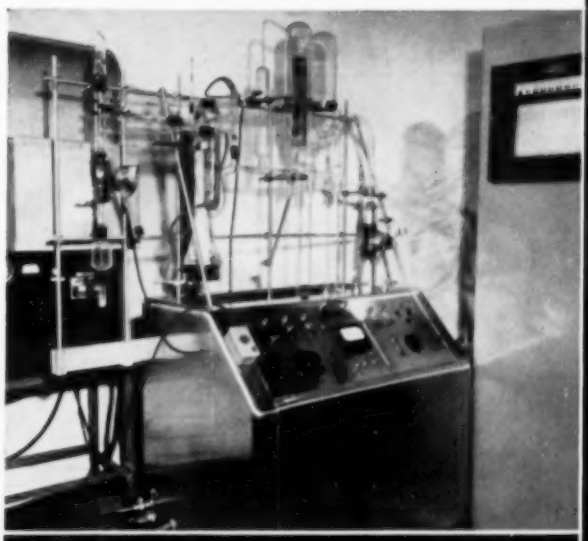

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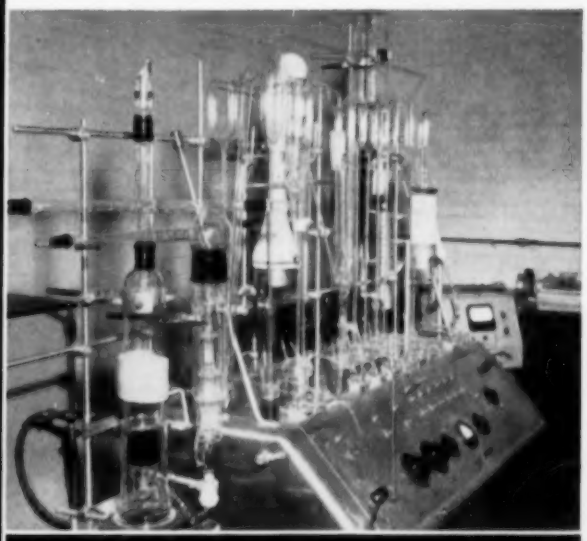

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tasks which do not require his technical training and he should be accorded individual and professional status commensurate with his contribution.

There must be opportunity for a continuation of education. It is important that professional employees be given opportunities to participate in activities of scientific and technical societies. It is important that they receive credit for their contributions to the advancement of technical knowledge or the profession as a whole.

There must be adequate communication between management and the professional employee. There should be organized orientation and training programs for new employees. Engineers need to understand the basic policies of their employer. They need to know their responsibilities and their opportunities for advancement. Adequate management-employee communications require a day-to-day relationship supplemented by periodic performance reviews, and other appropriate techniques.

Salaries must be established which will recognize the contribution of the professional employees as related to that of other groups. Salary differentials between various levels of technical experience have been substantially narrowed during recent years. Engineers who, after a period of satisfactory employment, find their salaries are only slightly higher than those of the recent graduate and possibly lower than those of a skilled craftsman are not working in a favorable atmosphere.

Management must minimize the fear of job insecurity by adopting feasible means for stabilizing the employment of professional personnel and suitable termination policies. Since many engineers become managers, there is a need to insure that they are employed and developed in an atmosphere which will fit them for their future responsibilities. Executive talents must be developed by experience and training in phases which lead to managerial responsibilities.

Engineering Societies' Responsibilities

The engineering societies must take the lead in the advancement of the profession. Among the basic responsibilities of the engineering societies are the establishment of standards of ethical conduct, rigid requirements for admission to membership, accreditation of educational institutions which grant engineering degrees, and awards and prizes in recognition of worthy contributions to the advancement of the profession.

The national engineering societies have an additional responsibility to foster a healthy professional climate for employed engineers. Their governing boards and their individual members should unite in exerting their best efforts toward solving the problem. These responsibilities are so challenging and so vital to the current problem that they must be considered as obligations.

Current efforts of national committees to encourage professional development of engineering society members and to promote recognition by the public of the professional character of the engineers' work should be expanded. An objective evaluation of the problem should be continued, followed by specific recommendations for the good of the profession. Engineering societies should adopt official statements for membership information with respect to collective bargaining to the extent permitted by their charters and constitutions. They should acquaint their memberships with those provisions of the Taft-Hartley Act which have a special significance to professional engineers. Constructive programs for encouraging professional consciousness on the part of engineers both before and after graduation should be sponsored. Therefore, the engineering societies and Engineers Joint Council should inform management as to the standards that will contribute to full professional achievement.

The engineering societies should provide guidance and assistance to educational institutions confronted with any problem which is detrimental to the achievement of full professional training of students.

Engineering Education's Responsibilities

Engineering colleges have a primary responsibility for developing professional concepts in engineering students. Professional concepts should be developed through their application to the solution of engineering problems in the technical courses, lectures, association with students, and by good example.

Opportunities for engineering educators to become better acquainted with the total environment in which engineers work should be expanded through temporary employment in nonacademic fields and the utilization of employers with "professional vision" in the classrooms and student seminars. Such activities enable students to appraise their status more realistically upon graduation.

Conclusions and Recommendations

There are obligations and responsibilities resting on both employer and employee. Each, of course, has responsibility to advance his own welfare. Beyond that, and yet a part of it, each has responsibility to the other and to society. Grave responsibilities for inculcating and developing professional consciousness in young members of the profession rest upon the educational institutions and professional societies. Various phases of such responsibilities have been stressed in the several sections of this report.

Without a sound technical foundation no man can become a competent engineer. But more than technical competence is demanded of one who expects to be recognized as a professional person. One must understand and observe appropriate ethical standards and it is important to cultivate proper understanding of such standards.

The ECPD program "The First Five Years of Professional Development" is an excellent step in the right direction. Here is opportunity for the engineering societies, the colleges, industrial management, and civic institutions to work together to aid young graduates in continuing their education and in adjusting themselves to conditions to be met in the practice of their profession.

The present report has been prepared with full realization that the subject refers chiefly to one phase of professional life. An attempt has been made to identify factors that have significant bearing on the specific problem under consideration. Concerted efforts by all concerned with advancement of the profession are required if satisfactory solution is to be found. It is believed that if the recommendations submitted are followed by those to whom they are directed, substantial improvement in the standing of the profession will result. There is no simple solution, but EJC recommends that:

1. Management utilize the services of engineers more effectively and thereby afford them opportunity for advancement and economic improvement.
2. Management recognize its responsibility to make engineers feel that they are a part of management.
3. Management survey areas of communication, recognition, and salaries and, where found wanting, correct to conform with standards of professional practice.
4. The engineer take inventory of his services and his actions to make sure that he has a professional attitude toward his work.
5. Engineering societies establish and employ appropriate means to maintain high standards of ethical conduct for professional achievement.
6. Engineering societies encourage the professional development of their members and promote proper recognition of the profession.
7. Engineering educators emphasize the characteristics of the profession.

RADIO'S ONE-WAY STREET

Dr. S. Weisbaum assembles an isolator which he developed for use in a new microwave system. Dr. Weisbaum is a Ph.D. in microwave spectroscopy from New York University. He is one of many young men at Bell Laboratories applying the insight of the physicist to develop new systems of communication.

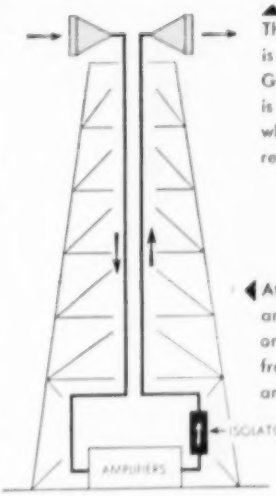
New radio relay systems for telephone and television now in the making will employ an ingenious device invented by Bell scientists. The device, known as an "isolator," senses which way microwaves are traveling through a waveguide, and stops those going the wrong way.

In the new systems a klystron wave generator sends signals through a waveguide to the antenna. The klystron must be shielded from waves reflected back along the waveguide by the antenna. The isolator stops reflections, yet allows the transmitted signals to go through clear and strong.

This isolator is a slab of ferrite which is mounted inside the waveguide, and is kept magnetized by a permanent magnet strapped to the outside. The magnetized ferrite pushes aside outgoing waves, while unwanted reflected waves are drawn into the ferrite and dissipated. This "field displacement" action results from the interplay between microwaves and a ferrite's spinning electrons. Bell physicists discovered this action during their fundamental studies of ferrites.

This is another example of how Bell Telephone Laboratories research works to improve American telephony and telecommunications throughout the world.

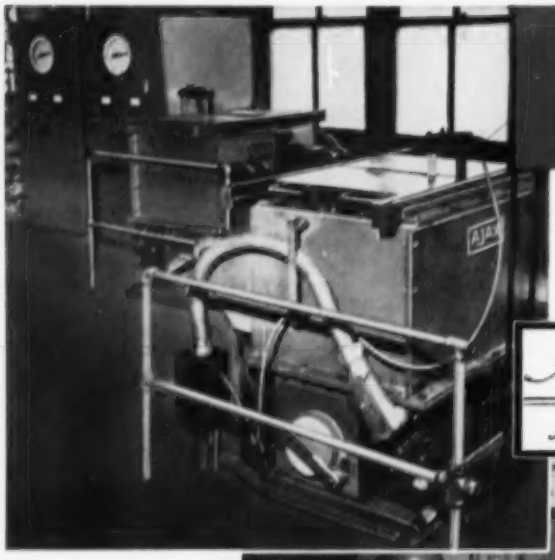
▲ The heart of the isolator is a ferrite slab. Geometric pattern is a carbon layer which dissipates reflected signals.



◀ At a radio relay station an isolator assures one-way transmission from the output of the amplifier to the antenna.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT



AJAX INDUCTION FURNACES

mean Higher Quality Castings for...

Advance
TOOL & DIE CASTING COMPANY

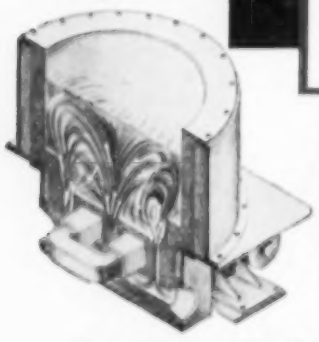
Aluminum DIE CASTINGS *Zinc Base*

View above shows AJAX melting furnaces, with control cabinets in background.

View showing AJAX-TAMA-WYATT 20 kW, 60 cycle induction holding furnace supplying metal at exactly the right temperature to die casting machines.

The Furnace That Stirs Itself...

The sectional view below shows the twin-coil stirring action of the 100 kW, 60 cycle AJAX Induction Furnace. Heat induced in the secondary channels below is conveyed throughout the melt by electro-magnetic circulation, as shown by the arrows.



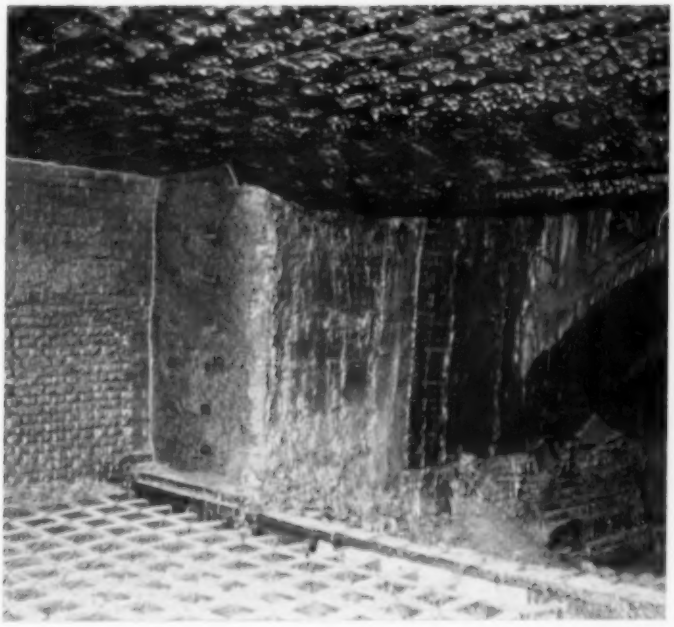
Inherent stirring action of these furnaces has proved most valuable to ADVANCE TOOL & DIE CASTING CO., Milwaukee, Wisc. In full operation for 3 years, the most important result of the use of these furnaces is higher quality die cast aluminum parts. The alloy is held in uniform solution, resulting in elimination of oxides, reducing hard spot trouble in secondary machining to a negligible factor. Temperature of the melt is held at 1170°F. through on-off control of the low power circuit. Working conditions are made more comfortable because of low heat losses. The units take up very little floor space.

AJAX
TAMA-WYATT

AJAX ENGINEERING CORP., TRENTON 7, N. J.

INDUCTION MELTING FURNACE

AJAX ELECTRO METALLURGICAL CORP., and Associated Companies
AJAX ELECTROTHERMIC CORP., Ajax Northrup High Frequency Induction Furnaces
AJAX ELECTRIC CO., The Ajax Hultgren Electric Salt Bath Furnace
AJAX ELECTRIC FURNACE CORP., Ajax Wyatt Induction Furnaces for Melting



RAMTITE®

Stands Severe Test of 435 Heats

in Open Hearth
Checker Chamber
Fantail Area Side Walls

RAMTITE was installed in the right and left corner walls of this open hearth checker chamber in May, 1955. Now, afer 435 heats, the walls are in excellent condition and have materially reduced refractory maintenance costs.

The wash of the gases under the nose and the scrubbing action across the face of the wall have caused little damage to the RAMTITE.

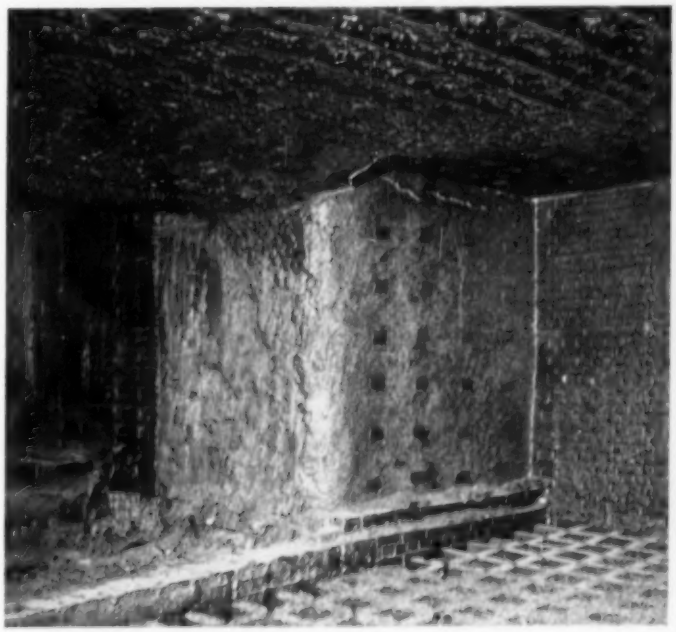
Expansion and contraction caused previous fire brick walls to bulge and separate at the outside corner and at the junction of the corner walls and side walls, leaving them as leaky as the proverbial sieve.

RAMTITE, being monolithic, is air-tight, gas-tight, and flame-tight—no air infiltration.

RAMTITE has proven that it can stand this severe service, and this company has expressed its satisfaction by making its second installation of RAMTITE corner walls.

Incidentally, all suspended checker chamber roofs and fantails at this mill are of RAMTITE construction.

Remember, RAMTITE IS OUR BUSINESS . . . NOT A SIDELINE. For more detailed information, call your local RAMTITE representative or mail coupon below.



These RAMTITE checker chamber corner walls were installed in May, 1955. Pictures were taken after 150 heats. Part of RAMTITE roof also shown.

The Ramtite Co.

DIV. OF THE S. OBERMAYER CO.

Manufacturers of Plastic Refractories and Gunning Materials for Steel Mill Furnaces

THE RAMTITE CO., Div. of the S. Obermayer Co.
1811 South Rockwell St., Chicago 8, Ill.

Please send the items checked:

- ☐ Bulletin on Castable and Gunning Refractories
- ☐ Steel Plant Bulletin

Company Name .....
Attn: Mr. ..... Title .....
Address .....
City ..... Zone ..... State .....

(Aluminum Company of America photo)

At one stroke this press can forge pieces 10′ wide or 24′ long. It can change a 2,000-pound aluminum slab into a complicated aircraft component . . . saving material as well as machining and assembly time. Cast and forged nickel alloy steels provide the strength and toughness needed in columns, cylinders, die-block holders and dies of this giant machine. Among the first of the facilities in the U. S. Air Force Heavy Press Program, this unit is a notable engineering achievement of United Engineering & Foundry Co., Pittsburgh, Pa.

Nickel alloy steels strengthen huge press for 35,000-ton squeeze

EIGHT 200,000-POUND FORGINGS of steel fortified with 2¼% nickel! That's what was specified to give this mammoth press essential strength. Used as four 2-column units, these forgings are subjected to the tremendous force of 35,000 tons.

Nickel alloy steel provides the level of strength and notch toughness required. These massive columns are each 61′ high and 34″ in diameter. Whenever a component's size restricts methods of heat-treating, or permits forging only limited portions at a time, improved strength and elastic properties depend particularly upon correct alloy content.

Nickel alloyed steels are used for still other parts that encounter high stresses and loads.

Dies and die holders gain needed stamina from additions of nickel. Among the largest steel castings ever used in press construction, the top and bottom die holders of this press are nickel-chromium-molybdenum steel approximating the 4340 composition. Each measures 26′ by 12′ by 25″ and weighs 350,000 pounds.

In many a metal, you can improve specific properties by use of nickel alone or in combination with other alloy elements. When you seek the solution to a metal problem, let us give you the benefit of our wide practical experience.

Send the details of your difficulty for our suggestions. Write us now.

INCO **THE INTERNATIONAL NICKEL COMPANY, INC.** 67 Wall Street New York 5, N. Y.

REPORTER

Basic Bessemer Plant for South Wales

Basic bessemer steel production has grown to over a million tons annually in the 20 years since the process was revived in the U. K. for production of low carbon rimming steels. Newest plant is that to be built by the Steel Co. of Wales with three 50-ton bessemer (thomas) converters using oxygen enriched air blast. All previous production was in open hearths. The new Port Talbot plant will permit reduction in blast furnace burden costs through production of two grades of pig iron. Bessemer iron is to contain about 1.6 pct P, while iron for the open hearths will have some 0.4 pct P. Steel from both processes will be used to increase output of flat products on the continuous wide-strip mill. The bessemer shop will raise plant's overall ingot capacity from 2.4 to 3.0 million long tons, and a new 30 ft 3 in. diam blast furnace, the company's fifth furnace, equal in size to the world's largest, will increase pig iron production by 10,000 tons per week.

All-Basic, Flat-Roof Open Hearth

Inland Steel Co.'s first all-basic, flat-roof open hearth has poured 240 heats with only a single patch so far. The patch was on the roof at the point where the oxygen lance is used and hot metal is poured into the furnace. This is the first flat-roof, all-basic open hearth using hot metal as part of the charge, although Keystone Steel & Wire Co. has a similar furnace in operation on cold charge at Peoria, Ill. Plant officials at Inland expect 390 heats from the all-basic roof before replacement, in contrast to an average life of 141½ heats for arched silica brick roofs in the same open hearth shop.

Climax to Double Molybdic Oxide Capacity

With a heavy demand for high quality molybdic oxide for petroleum catalysts, the powder metallurgy industry, and corrosion and heat resistant alloys, Climax Molybdenum Co. is adding a second sublimation furnace at its Langeloth, Pa., plant. The furnace is expected to be in operation in September, doubling the company's present 2.7 million lb capacity for high purity oxide.

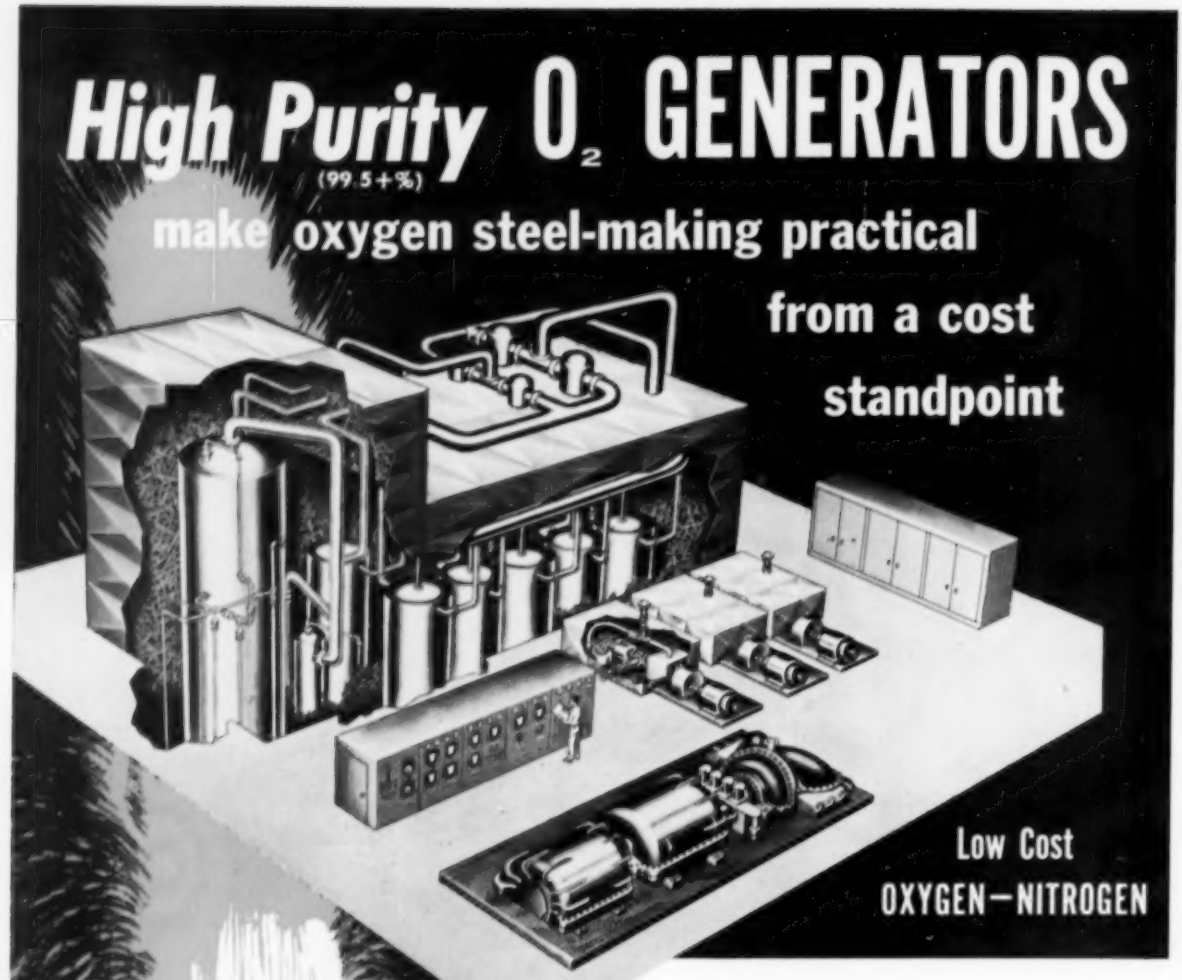
Vacuum Remelting and Casting Facilities to Gain

Allegheny Ludlum Steel Corp. is doubling its capacity for vacuum remelting high-temperature alloys in consumable electrode furnaces. Completion of this expansion at Watervliet, N. Y., to enable firm to remelt 1.5 million lb per month, is expected by year's end. At the same time, Allegheny announced sale of technical knowledge and patent rights for the consumable electrode vacuum remelting process to Midvale-Heppenstall Co. . . . Experimental vacuum casting of large forging ingots will start at U. S. Steel's Duquesne Works this summer. Techniques being used for first time in U. S. improve quality of heavy forgings by reducing amount of trapped gases in the steel. Hot metal will be poured into the 31 ft high, 17 ft diam casting chamber at 3 to 10 tons per min. The vacuum can be broken after solidification, but ingot cooling requires at least two days.

High Purity O_2 GENERATORS

(99.5+%)

make oxygen steel-making practical from a cost standpoint



One of the important new uses of oxygen in steel-making is its application in Top Blown Converters for the production of high quality steel at lower cost. This process is now being successfully employed here and abroad and holds a prominent position in the expansion plans of the industry.

For this and other large volume uses of oxygen in the steel industry, we are prepared to design and build "On-Location" Oxygen and/or Nitrogen Generators to fulfill your particular requirements on a lease basis—*without capital investment.*

We design and build:

Large Capacity Tonnage Generators, regardless of size, purity, high or low pressure cycle, with liquid oxygen pumps, if your oxygen should be under pressure

or

"Packaged" High Purity Generators, producing high purity oxygen and nitrogen simultaneously—oxygen delivered safely under pressure by Air Products patented liquid oxygen pumps.

Send us details regarding your requirements and we will give you actual figures on the savings you can expect with an "On-Location" Generator installed at your plant.

Air Products
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Dept. V Box 538, Allentown, Pa.

AS PARTNERS IN YOUR PROGRESS . . .

OUR CONSCIENTIOUS SERVICE – is a *plus* factor!

Our service engineers are thoroughly familiar with electrothermic and electrochemical operations. They are competent to render high level technical advice to electrode, anode, carbon brick and mold stock customers.

The alertness of these service engineers in anticipating customer needs and wishes is a characteristic *plus factor* in the trustworthiness of GLC carbon and graphite products.

The high degree of integration between discoveries in our research laboratories, refinements in processing raw materials and improved manufacturing techniques is further assurance of excellent product performance.

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Great Lakes Carbon Corporation

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The Columbium Shortage Is Over!

"Electromet" Ferrocolumbium

is now available for Stainless Steel and High-Temperature Alloys

The development of high-speed aircraft has produced a wide-spread demand for high-temperature alloys containing columbium.

Now that the government stock-piling program on columbium has been completed, ample supplies of columbium are once again available for defense and civilian uses. This is important news, as industry may now use this valuable alloying element to attain good high-temperature properties in stainless steel and non-ferrous alloys.

Columbium is added to austenitic chromium-nickel stainless steels to prevent intergranular corrosion and improve strength at high temperatures. A columbium addition of 10 times the carbon content will stabilize stainless steels at temperatures of 800 to 1600 deg. F., thus preventing impairment of corrosion resistance and physical properties. In the high-temperature alloy field, 0.2 to 4.0 per cent columbium will preserve the strength of super-alloys during long exposures to temperatures up to about 1550 deg. F., or slightly higher.

ELECTROMET furnishes columbium in two forms: ferrocolumbium and ferrotantalum-columbium. Ferrocolumbium contains 50-60 per cent columbium, while ferrotantalum-columbium contains approximately 40 per cent columbium and 20 per cent tantalum. Both of these ferro-alloys are available in a number of crushed sizes and give a 90 per cent recovery of columbium.

For further information about ELECTROMET columbium alloys, please contact the nearest ELECTROMET office listed below.

Columbium-bearing stainless steels are widely used in chemical equipment where resistance to corrosion at high temperatures is necessary.

Electro Metallurgical Company

A Division of Union Carbide and Carbon Corporation

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National Committee Celebrates Bessemer Centennial

Toneson Braithwaite, 88, of Pittsburgh, receiving a memento as the oldest bessemer steel blower from AIME Bessemer Steel Committee Chairman, A. B. Wilder. Left to right are: E. J. Lichy of J&L; D. R. Loughery of J&L; Mr. Braithwaithe; A. B. Wilder of National Tube; L. F. Sattele, assistant general superintendent of the host plant, National Tube's Lorain, Ohio, Works; and R. E. Edwards of J&L.

HONORING the One Hundredth Anniversary of the pneumatic converter process, the AIME Bessemer Steel Committee met on April 25 at the Lorain, Ohio, Works of National Tube Div. Members spent the forenoon observing modern bessemer operations under the guidance of Bessemer Supt. L. T. Sanchez. Off-the-record discussions during the afternoon featured an exchange of information by committee members on recent technological developments at their respective plants.

Lunch was served in the plant auditorium, and members were officially welcomed on behalf of National Tube by Assistant General Supt. L. F. Sattele. Committee Chairman A. B. Wilder, Chief Metallurgist of National Tube, took charge of the business meeting, chief item of which was a proposal to change the name of the group to Pneumatic Converter Committee in view of the expansion of the scope of the process beyond the bounds of the bessemer converter proper.

The meeting marked the culmination of a six-month search for the oldest living bessemer steel maker in the U. S.

Toneson Braithwaite, 88, of Pittsburgh, a retired employee of Jones & Laughlin Steel Corp. was introduced by D. R. Loughry, J&L staff industrial engineer, as the oldest bessemer blower, and "possibly the oldest steel maker in the world." He is shown in the photograph on this page receiving a memento of the occasion from Committee Chairman Wilder.

Pioneer steelmaker Tony Braithwaite, whose lifetime has practically spanned the steel industry from its near infancy to its present size, started his career at the Bellaire Iron Co., Bellaire, Ohio, in 1883. Three years later, he joined Jones & Laughlin at the Pittsburgh Works where he helped build the bottom on the plant's first converter and helped make the first blowout in the relatively new process. These were the days when bessemer converters lit up the Pittsburgh skies in so spectacular a fashion that "you could stand on any street corner and read your newspaper," according to contemporary accounts.

Born in Wales, a center of coal mining and steelmaking, Mr. Braithwaite came to this country at the age of 12. He served with Jones & Laughlin continuously as a blower from 1886 to 1930, converting countless thousands of tons of iron into bessemer steel. He still remembers with great clarity his early steelmaking days. "You had to feel your way in making steel in those days," he said. "I used to 'read' the heat without any instruments or anything. I did it without blue glasses."

One Hundred Years of Bessemer Steelmaking

by A. B. Wilder

We study the past
Because it is a guide to the present
and a promise for the future.
The struggle for a better world is strengthened
By the hopes, ambitions, and deeds
Of those who were before us.
As we look backward
Our attention is directed forward.

ONE hundred years ago, the manufacture of steel from molten pig iron without the use of fuel first began. In the earlier part of the nineteenth century the crucible process was the principal steelmaking method. It was a costly process, producing only a few pounds of steel at a time; so, most of the ferrous metal output was in the form of wrought or pig iron. With the perfection of the converter technique it became possible to produce low cost steel by the ton, thereby completely changing the structure, not only of the ferrous metal industry, but also of industrial production in general. This was the turning point from the *Iron Age* to the *Age of Steel*.

William Kelly (Fig. 2), Sir Henry Bessemer (Fig. 1), and Joseph G. Martien experimented with the process before 1856. William Kelly began in Eddyville, Ky., in 1847 and has been given credit for first discovering the principle of the pneumatic converter process. Several years later in England Henry Bessemer independently conceived a steelmaking process similar to Kelly's. Bessemer made public his invention at the annual meeting of the British Association for the Advancement of Science held at Cheltenham, England, August 1856. As a result of his paper, "On the Manufacture of Malleable Iron and Steel Without Fuel," and his progressive leadership in the years to follow, the process became permanently identified with the name, Bessemer.

Fig. 1—Sir Henry Bessemer

Credit for the commercial adaptation of the process must be given two additional persons. Robert Mushet (Fig. 3) in 1856 in England recognized the necessity of deoxidation and recarburization of the converter product and evolved the technique for adding high manganese iron following the blow. In Sweden, in July 1858, G. F. Göranson

produced steel under license from Bessemer, but the success of the process was dependent upon Göranson's redesign of the converter, increasing the tuyere area and decreasing the air volume.

Competition With Other Steelmaking Processes

After the acid bessemer process had been successfully developed, the open hearth and electric furnace processes were introduced. The first acid open hearth furnace in the U. S. was built in 1868. The basic steel making process in the U. S. began in 1884 in a basic-lined bessemer converter at Steelton, Pa., and the first basic open hearth steel was produced in the U. S. at Homestead, Pa., in 1888. The first electric arc furnace used for the production of steel was patented by Sir William Siemens in 1879.

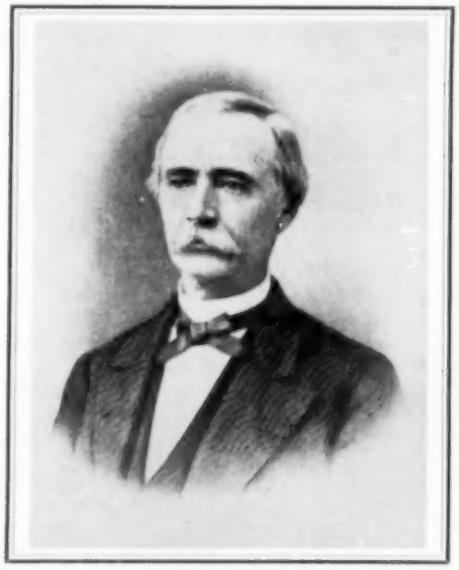

Fig. 2—William Kelly

Before 1900 open hearth steel was little used for the production of rails, and the replacement of iron rails with steel rails, as well as the rapid expansion of the railway network, provided an opportunity for the development of the bessemer process.

In 1887 when 500 tons of bessemer steel welded pipe were first produced by the Riverside Iron Works, Wheeling, W. Va., a new era developed for the bessemer process. The decision by National Tube Works Co. to abandon the production of wrought iron pipe and build a bessemer steel plant in 1890 was the beginning of events which led to the production of large quantities of bessemer steel for welded pipe. At the same time, seamless pipe was being introduced. Seamless pipe, however, was made from open hearth steel, and contributed toward the development of the open hearth process. Only during the past 15 years has seamless pipe been commercially produced from deoxidized bessemer steel.

During the period 1900-1910 the production of open hearth steel surpassed bessemer steel (Fig. 4). Part of the reason for this development was due to the almost complete change over from the use of bessemer to open hearth rails.

A. B. WILDER is Chief Metallurgist, National Tube Div., U. S. Steel Corp., Pittsburgh, Pa. This paper was presented at the New York meeting, February 1956.

The growth of the automobile industry and the use of flat steel products had a great influence on steel producing processes. Prior to 1920 the steel industry was principally a producer of heavy products, but in 1924 John Tytus developed the continuous hot strip mill, and this process provided an outlet for large quantities of open hearth steel, much of which was destined for the automobile.

During the past 25 years the production of open hearth steel in the U. S. (Fig. 4) has out distanced the production of bessemer steel for the following reasons:

1) The open hearth process provides a greater utilization of scrap.
2) The nitrogen and phosphorous content of open hearth steel is lower.
3) The high capacity of open hearth furnaces has been increased still further in recent years.
4) The open hearth process is relatively versatile with respect to raw materials and fuel.
5) Basic open hearth steel is economically produced from iron of intermediate phosphorous content.
6) Open hearth steel, because of relatively high uniform quality, is widely accepted in specifications and codes.
7) Carbon may be caught on the way down in the open hearth; thus, it is possible to melt many different grades of steel within narrow chemical limits.
8) The open hearth requires less iron and coke production facilities.

Fig. 3—Robert Mushet

In Western Europe the trend has been quite the opposite, for the basic bessemer process has retained its position as a major process for producing carbon steel (Fig. 5). The smelting of high phosphorous ores on the Continent results in high phosphorous pig iron ideally suited for processing in the basic converter. The resulting slag serves as a valuable fertilizer because of its phosphorous content. Further, the high cost of fuel and the relatively low avail-

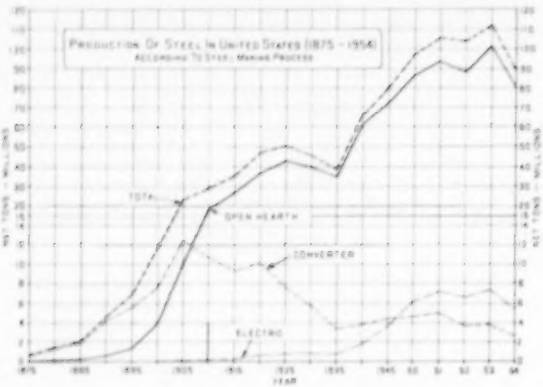

Fig. 4—Steel production according to process in the U. S.

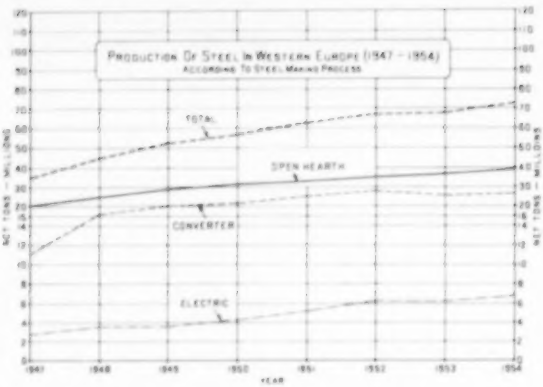

Fig. 5—Steel production according to process in Western Europe.

ability of scrap in Europe has favored the basic converter.

The open hearth and electric furnace process require a considerable time to produce a heat, although with expanded furnace capacity each heat consists of a considerable volume of steel. While the energy efficiency of the open hearth has been improved, the Btu requirements remain high and can not compete with the converter. It will, however, be necessary for converters to follow a pattern of increasing capacity. The production of tonnage oxygen at low cost is largely responsible for the present progress in the production of converter steel, for this has not only made it possible to control the nitrogen content, but also provided the possibility of melting increased quantities of scrap.

The control of industrial fumes has been a problem in many areas, and considerable progress has been made in this field during recent years. Today, it appears that fume control methods for most metallurgical processes are feasible; however, the problem of fume collection and control in present day bottom-blown converter plants is uncertain due to the design of plants and the nature of operation, particularly when oxygen is employed.

The nitrogen factor has had a fundamental relationship to the development of the pneumatic converter process; it was recognized by F. W. Harbord and T. Twynam[1] as early as 1896. Nitrogen is undesirable in many types of steel, particularly where toughness is a factor. It has taken years to evaluate the influence of nitrogen in steel, but its behavior is now well understood, and methods have been developed for controlling the amount and behavior of nitrogen in converter steel. The fixation of nitrogen with aluminum is well recognized. The control of nitrogen by surface blowing with oxygen enriched air and oxygen-steam mixtures is now used on a commercial basis.

It has been said that the pneumatic converter process lacks control due to the fact that it is possible to blow a heat of steel in 10 to 15 min. Also, in making converter steel it is quite difficult to catch carbon on the way down. These problems have long been recognized,[2] but it should be pointed out that many grades of steel can be made by the converter process with a high degree of control. This is particularly true with capped and rimmed low carbon steels, but to gain closer control for other grades a greater length of time for making the blow might be considered. This may be achieved in the surface blown vessel by not only controlling the volume of air or oxygen, but also by changing the depth of bath. With increased time the bath and slag may be adjusted to produce the desired result, and the temperature may be determined and controlled, but it may be necessary to utilize larger converter units approaching those of the conventional open hearth size. Thermal losses in the larger converters would control the length of blow.

Although duplexing (using bessemer blown metal in the open hearth) is widely used, the process has certain limitations. When the converter is blown very young and silicon is removed, a duplex open hearth product low in nitrogen is produced. Blast furnace iron may be desiliconized in a ladle with oxygen if a converter is not available. When fully blown converter metal is used, the duplex open hearth product will contain nitrogen which may be fixed by aluminum deoxidation. The bath boiling technique may also be used to reduce the nitrogen content of duplex open hearth steel. Duplex steel can always be used for applications in which nitrogen is not objectionable.

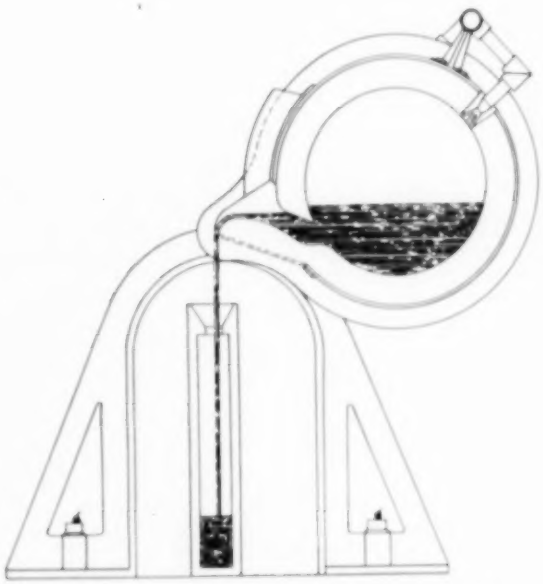

Fig. 6—Early bessemer converter with small tuyere area.

The Age of Steel

The steel industry as it exists today had its beginning in 1856 with the development of the bessemer process for the low cost conversion of iron into steel. The early history of the process is recorded in the patent literature, and a brief summary of the more significant claims is presented:

Henry Bessemer, London, England; English Patent 356, February 12, 1856, and U. S. Patent 16082, November 11, 1856.

The conversion of molten iron or of remelted pig iron into steel or into malleable iron (Fig. 6) without the use of fuel for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the particles of a mass of molten iron a current of air, oxygen, or gaseous matter containing or capable of evolving sufficient oxygen to keep up the combustion of the carbon contained in the iron until the conversion is accomplished.

Joseph G. Martien, Newark, New Jersey; U. S. Patent 16690, February 24, 1857.

The purification or conversion of fluid or molten iron, subjecting the molten iron to the action of atmospheric air, steam, or other gaseous body or chemical agents, in any form capable of evolving oxygen or other purifying gas, in such a manner as to cause the air, steam, or other solid, liquid, or gaseous body to impinge upon, penetrate through, or search among the metal while it is flowing.

Robert Mushet, Coeford, England; English Patent 2220, September 22, 1856, and U. S. Patent 17389, May 26, 1857.

The addition of a triple compound or material of, or containing, iron, carbon, and manganese to cast iron which has been purified and decarburized by the action of air in a molten or fluid state, or in any convenient manner, so as to become mixed and combined in the process of manufacture in order, by the union of the substances, to obtain malleable iron and steel.

William Kelly, Eddyville, Kentucky; U. S. Patent 17628, June 23, 1857.

Blowing the blasts of air, either hot or cold, up and through a mass of liquid iron, the oxygen in the air combining with the carbon in the iron causing a greatly increased heat and boiling commotion in the fluid mass and decarburizing and refining the iron.

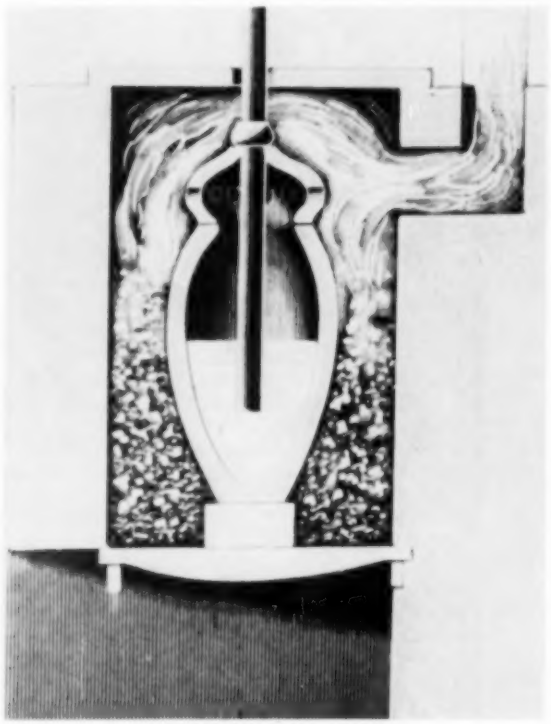

Fig. 7—The first bessemer converter.

Sir Henry Bessemer performed his first experiments in the vessel shown in Fig. 7, produced steel in this vessel in 1855 and made his first public announcement of the process on Aug. 11, 1856. In 1858 Bessemer erected a converter at Sheffield, England (Fig. 8), which was an improvement over previous vessels. The use of spiegeleisen as proposed by Robert Mushet made it practical to produce steel on a commercial basis by the converter process. In 1863 Bessemer patented the first detachable bottom (Fig. 9). Other early bessemer converters are shown in Figs. 10 and 11.

During the period in England when Sir Henry Bessemer was developing his process for steelmaking, developments were taking place in the U. S. and on the Continent. Sweden in 1864 produced 3178 tons of bessemer steel and 4500 tons of crucible steel; the French in 1866 were manufacturing bessemer steel in six plants and produced 10,791 tons.

The Kelly steel converter shown in Fig. 12 was experimentally used by the Cambria Iron Works in 1861 and 1862, but Kelly had previously constructed other converters in Ky. The Kelly Pneumatic Process Co. began building a plant in 1862 at Wyandotte, Mich. W. F. Durfee, manager of the plant, made steel by use of the Kelly and Mushet patents in a 2½-ton converter in Sept. 1864. This was the first steel made on a commercial basis by the pneumatic converter process in U. S.

In 1864 Alexander L. Holley organized the Albany and Rensselaer Iron and Steel Co., and under the Bessemer and Mushet patents made steel in a 2½-ton converter at Troy, N. Y., in February 1865. Later two 10-ton converters were constructed at this plant. In 1866 the two companies at Troy,

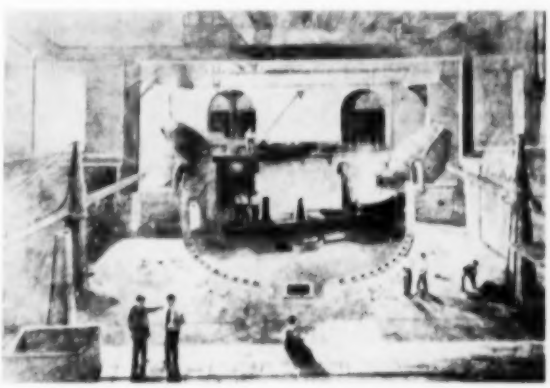

Fig. 8—Bessemer converter plant in 1858.

N. Y., and Wyandotte, Mich., were consolidated into the Pneumatic Steel Ass'n. Licenses were then obtained by other producers and plants of a larger capacity were rapidly erected throughout the U. S. in the years to follow. This consolidation of Bessemer, Kelly, and Mushet interests eliminated the controversy in America regarding the process.

The Basic Bessemer Process

On the Continent steel makers faced with the problem of treating many high phosphorous iron ores did not find the bessemer process entirely satisfactory and set about trying to modify the process to treat these raw materials. In 1860 Turner in Germany recommended a basic converter lining consisting of burned magnesite. Wedding in 1865 proposed removal of phosphorus in an acid converter by removing the slag after oxidation of silicon, and then oxidizing the phosphorus and removing the slag. Dephosphorization, however, was prevented by the presence of a silica lining, and the second slag contained no phosphorus. In 1877 Krupp in Germany and Bell in England initiated the first step toward a solution of the problem. They charged pig iron into a special revolving furnace and re-

moved phosphorus by use of iron and manganese oxides as a lining and flux.

The next step was taken in 1878 by an Englishman, Sidney Gilchrist Thomas, when he manufactured basic dolomite bricks and reported at a meeting of the Iron and Steel Institute that he was able to remove phosphorus from bessemer steel. Later Thomas observed that limestone could be satisfactorily used as a flux. In 1879, with a basic lining consisting of bricks and a rammed bottom and the use of a basic flux, Thomas observed the necessity of an after-blow at the completion of decarburization. The success of the basic process utilizing the iron from high phosphorous ores in Germany was thus assured with 1) a basic lining, 2) basic flux, and 3) an after-blow. There was no essential difference between the design of a basic and an acid converter.

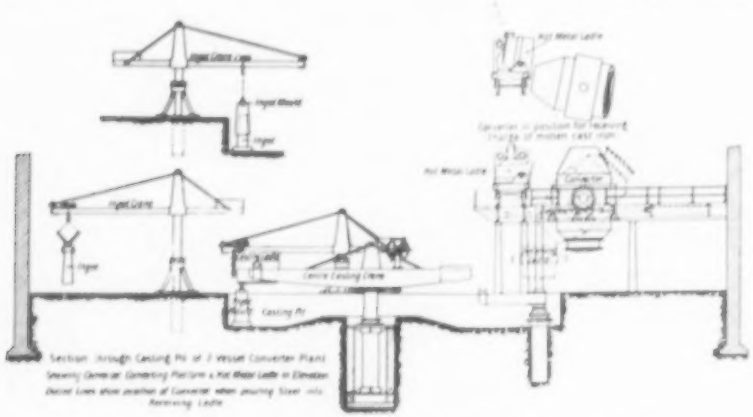

Fig. 17—A two-vessel bessemer steel converter plant in 1900 looked like this.

Steel made in a basic converter was later called *Thomas* steel, while the product of the acid converter was called *Bessemer* steel. In addition to Thomas, there were Percy C. Gilchrist (his cousin) and George J. Snelus of England, and Jacob Reese of Pittsburgh, Pa., who were interested in the development of the basic process. Reese obtained a patent in U. S. in 1866, and in 1872 Snelus discussed the process at a meeting of the Iron and Steel Institute in London. The basic converter process developed rapidly in Germany due to the availability of suitable ores and the use of slag for agricultural purposes. In 1884, there were 32 steel works with 88 basic converters throughout the world with a combined vessel capacity of 795 tons; in Germany alone there were 41 of these converters.

Surface Blown Foundry Converter

In 1862 Bessemer patented a side blown tiltable converter shown in Fig. 13. The tuyeres were placed through the side all around the bottom of the vessel. In Sweden there were a number of fixed converters operated with tuyeres on the side near the bottom. Later the tuyeres were gradually raised from the bottom but maintained below the surface of the molten metal.

In the Waldren converter (Fig. 14), designed in 1884, there was a distinct departure from the other converters with tuyeres all around the circumference. Waldren placed four tuyeres on one side close together but slightly inclined from the center to provide for rotation of the liquid metal.

In later designs the tuyeres on the sides of the converters were gradually raised toward the surface. Finally, F. A. Tropenas designed a converter (Fig. 15) with the blast directed upon the surface from the side of the converter. In the Tropenas patent of 1891 two rows of tuyeres are shown. In later years the top row of tuyeres was found to be unnecessary.

Developments from 1890 to 1940

Following the development of the surface side blown converters there were only a limited number of fundamental changes in bessemer steelmaking during the next 50 years. The improvements which occurred were essentially of a mechanical nature largely directed toward material handling, although many new plants were constructed with a trend toward larger converters.

There were a number of small side blown converters of 2-ton capacity in 1900, but these were used primarily in the production of steel castings and were not practical where facilities existed for open hearth or bessemer steel production. Production facilities for bottom blown bessemer converters did not exceed 20 tons in capacity. The eccentric and concentric types of converters employed at the time of Sir Henry Bessemer's death in 1898 are shown in Fig. 16. Detachable bottoms and equipment for rotation were used, and the air blast was provided by horizontal double cylinder engines. A typical bessemer plant in 1900 is shown in Fig. 17. The U. S. Steel Corp. in 1901, for example, operated 35 bessemer converters ranging in size from 5 to 17 tons with a combined capacity of 7.5 million tons. Several 10-ton bessemer converters are shown in Fig. 18 in operation at McKeesport, Pa.

During the period 1910-1930 a number of bessemer plants were built in conjunction with tilting open hearth furnaces. The blown bessemer steel when added to the open hearth permitted more open hearth steel to be melted and, as a result, increased open hearth capacity. The converters were also used for the production of bessemer ingots. Larger vessels were installed, and the air blast was supplied by centrifugal blowers. Adequate mixers were provided, and metallurgical practices were improved. Converters of 30-ton capacity were operated with production rates of 40,000 tons per month. The number of tuyeres was increased with the use of larger volumes of air. With the larger production rates, mass handling of material was improved.

During the 1890-1940 period considerable attention was directed toward the control of temperature during the bessemer blow and the state of oxidation at the end of the blow. High temperatures at the end of the blow not only increased the oxygen con-

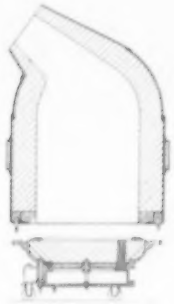

Fig. 9—Detachable bottom, 1863.

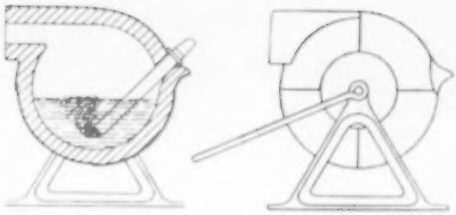

Fig. 10—Early bessemer converter.

Varying Converter Shapes Over the Century

Fig. 11—Early bessemer converter with large tuyere area.

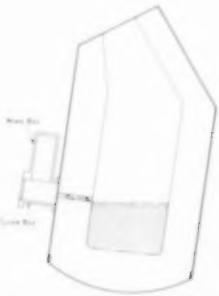

Fig. 32—Side blown foundry converter of present day.

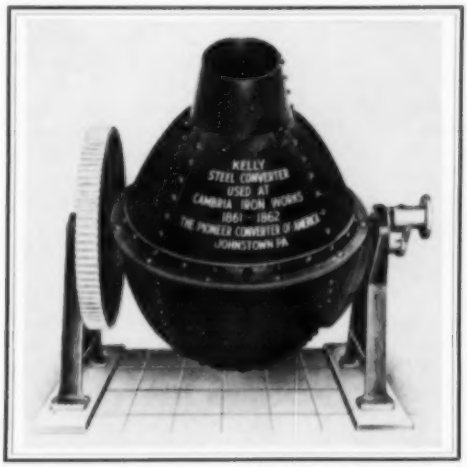

Fig. 12—Kelly converter, 1861 (R. Earl Penrod).

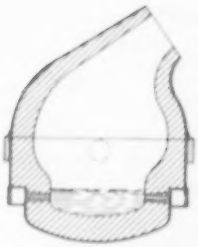

Fig. 13—Bessemer side blown converter, 1862.

Fig. 20—Modern European basic converter with monolithic lining.

Since the earliest designs of Bessemer and Kelly, the size and shapes of the pneumatic converter has changed to meet the varying ideas of steelmakers. The detachable bottom was a significant innovation . . . large tuyere areas were found necessary . . . side blowing techniques have been tried repeatedly since the earliest days . . . and today opinion still varies on what is the best size and shape of converter profile and the best location and design of tuyeres.

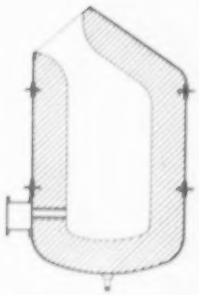

Fig. 14—Waldren side blown converter, 1884.

Fig. 19—European 25-ton acid converter of present day.

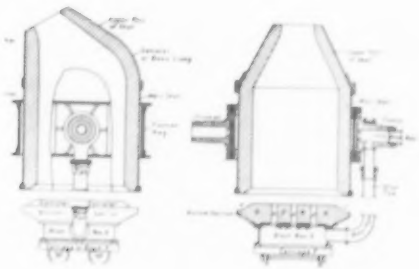

Fig. 16—Eccentric and concentric converters, 1898.

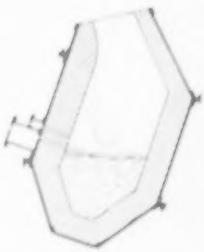

Fig. 15—Tropenas side blown converter, 1891.

tent of the blow, but also its nitrogen content. Composition of the molten iron and steel, the use of coolants, and the mixing of additions were other factors which received attention.

Special Bessemer Practices

Iron quality, temperature, handling, separation of blast furnace slag, slopping, lining life, and temperature of the blow are important factors in modern converter practice.[7] Titanium in iron and variations in blowing pressures are reportedly undesirable. Attention has been directed over the years to kidney (lining build-up) formation. All of these factors are related to converter design and methods of operation.

Among the many modifications in bessemer steelmaking, a process for producing seamless steel pipe was developed in 1940 by Wright. In this process molten pig iron is used for deoxidation of the bessemer blow. In 1940, R. Perrin[8] developed a method for dephosphorizing steel by pouring it from a height into a ladle with a basic oxidizing slag. After additions of silicon and manganese the steel is poured into an acid converter and blown. In the Yocom[9] process, completely blown metal is poured into a dephosphorizing ladle, with lime, iron oxide, and flux introduced during pouring. In the manufacture of wrought iron by the Aston process, the blown acid converter steel is required to be low in sulfur, and White and Storey[7] developed a process in which molten iron is poured into molten caustic soda to remove sulfur. The iron is then blown in an acid converter to remove metalloids. There have been many other methods developed for desulfurization of iron which may be used for production of converter steel.

In the Ugine-Perrin[8] process, developed in 1939, basic bessemer steel is poured into a ladle of lime-alumina slag. This synthetic slag is melted in an electric furnace. During pouring of the blown metal, additions of aluminum, ferrosilicon, etc. are made to the stream of metal. In order to provide sufficient heat at the end of the bessemer blow it may be necessary to add ferrosilicon and blow before pouring into the ladle of lime-alumina slag.

Fume

The nature of converter fume has been reported by several investigators.[9-12] One theory is the formation of iron carbonyl (FeCO) which burns in air to form FeO and CO_2, but brown fumes have also been explained by vaporization of iron which oxidizes in the air. It has also been observed that in order to reduce fume when oxygen blowing, a certain amount of steam is effective. The large volume of gas in the converter process, with dilution and variations in volume, influences efficient removal of brown fumes.

P. J. Leroy and L. Septier have shown that dust concentration with oxygen may be 0.0045 lb per cu ft and with steam-oxygen 0.0027 lb per cu ft. They indicate that particles vary from a spheroidal shape of about 0.05 μ to various proportions of 0.1 to 5.0 μ, with average dimensions of 1 μ.

In the oxygen lance process at Linz, Austria, the fume consisted of 93 pct Fe_2O_3 and MnO, CaO, and SiO_2. The particle size was 5 pct over 1.0 μ, 45 pct 0.5 to 1.0 μ, and 50 pct under 0.5 μ, and about 25 lb of dust were produced per ton of steel. In the basic bessemer process with oxygen enriched air, 50 lb of dust per ton of steel were produced, and the density of the dust is such that 15 cu ft may be discharged from a 30-ton heat.

H. Kosmider and coworkers determined the composition of dust during a basic blow. In the first period with air blowing, the dust contained 25 pct Fe and 5 pct Mn. The second period dust, with oxygen enriched blast, contained 50 pct Fe and 2.5 pct Mn. During dephosphorization with air blowing the dust contained about 50 pct Fe and 10 pct Mn, and the fumes were brown due to the oxides. Maximum temperature calculations at the interface of the gas and metal in a gas bubble indicated a temperature of 4175°F, but when the oxygen content was increased to 100 pct, the temperature was 5525°F. Temperatures of 3550°F were obtained with steam-oxygen mixtures (1:1.2). Particle size was difficult to determine due to coagulation, but particles 0.5 to 2.0 μ were observed. The dust content of the waste gases at the beginning of the blow were 0.35 g per cu m, and at the end of the blow 0.90 g per cu m.

The wet washing method is usually employed for fume control in top blown oxygen converter plants. Gases leaving the converter exceed 3000°F and are collected in a water cooled hood about the mouth of the converter. Dilution with air lowers the temperature of the gases, and they pass from the hood into a spark arrester at a temperature of about 1500°F. The gases then go through water sprays and finally through a disintegrator for final cleaning. At the Linz plant in Austria a waste heat boiler is used above the mouth of the converter, and the gases then pass into a wet washer.

Converter Blow Control

For more than 75 years attention has been directed toward control of the bessemer blow.[7] The

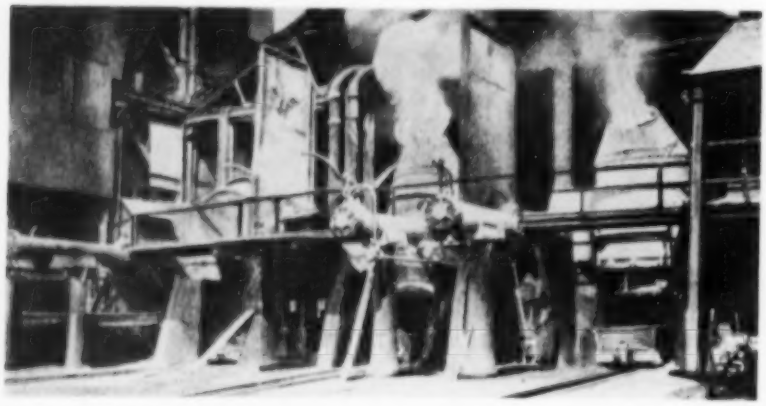

Fig. 18—During the fifty year period from 1890 to 1940 there were only a limited number of fundamental changes in bessemer steelmaking, although there was a trend toward larger converters. The figure shows 10-ton acid bessemer converters in operation at McKeesport, Pa. in 1890.

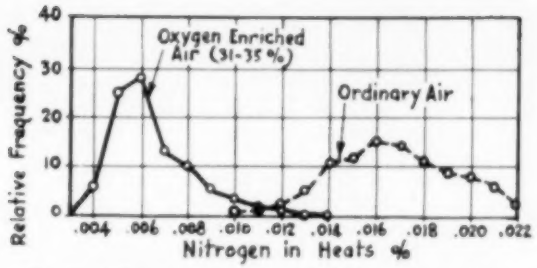

Fig. 21—Influence of oxygen enriched air on nitrogen content of thomas steel—Graef.

spectroscope is being used with success, but the most common method of turning down the vessel is by visual observation of the flame with colored glasses. H. K. Work[14] in 1940 developed a photocell end point control which is also being used for turning down the vessel.

The radiation pyrometer has been experimentally employed by many investigators. Insertion of the instrument in the tuyeres or the mouth[15] of the converter has been used. Temperature measurements may be checked with a thermocouple in the molten steel.

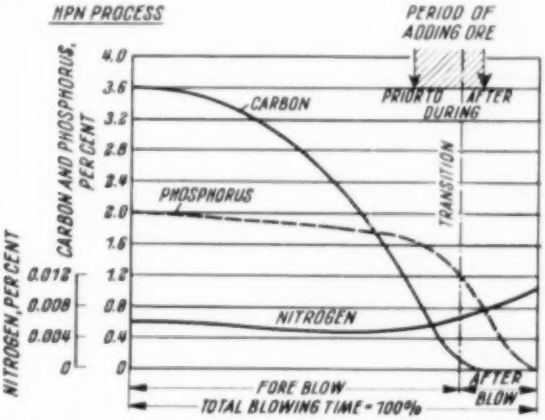

Fig. 22—Variation of nitrogen with time when ore additions are made during the blow (HPN process) in Germany—Weyel & Kosmider.

P. J. Leroy and coworkers[15] have recently made an extensive study of converter instrumentation (see p. 764). Slopping in a basic vessel has been controlled by a new type of flowmeter for regulation of wind. A pyrometer in the tuyere box and a flame pyrometer have been used for temperature measurement. For determining the end point, the transmission rather than emission characteristics of the flame were studied, and the opacity of the flame was also measured. These developments have been applied to the production of thomas steel on the Continent.

Low Nitrogen Steels

With the increased production of hot and cold rolled strip on continuous wide strip mills in Europe, it has become necessary to improve the deep-drawing qualities of thomas steel by reducing the nitrogen content. Much attention has been drawn toward modification of existing equipment, as shown in Figs. 19 and 20.

The production of converter steel with a low nitrogen content depends upon a number of factors including: 1) low partial pressure of nitrogen, 2) minimum contact of the blast and metal, and 3) low finishing temperature. Application of these principles includes a shallow bath or surface blowing, wide nose vessels to reduce back pressure, ore or scale instead of scrap for cooling, close control of the finishing temperature, and use of oxygen enriched air.

Oxygen enriched air has been used for the commercial production of converter steel since 1931, and Bessemer in 1856 recognized its possibilities. Oxygen reduces the nitrogen content of the steel by reducing partial pressure of nitrogen in the blast (Fig. 21) and also melts additional scrap. A process developed by Morrison,[16] consisting of blowing initially with air and finishing with oxygen enriched air, is of particular interest. Oxygen enriched air has also been used following the start of the carbon flame to melt additional scrap.[17]

The use of ore in the HPN process in Germany at Duisburg-Hamborn or the use of scale in the LNP process at Corby, England, (Figs. 22, 23) and close control of the finishing temperature have made it possible to reduce nitrogen by 50 pct to a level of 0.008 pct. This reduction is due to the low partial pressure of nitrogen in the gas bubbles resulting from action of carbon in the iron with ore or scale.

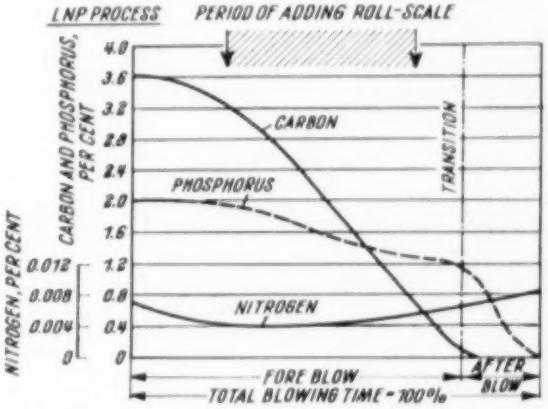

Fig. 23—Variation of nitrogen with time when scale additions are made during the blow (LNP process) in England—Weyel & Kosmider.

Mannesmann Röhrenwerke in Germany produced low nitrogen steel in an MA converter. This converter was side blown beneath the surface of the metal and provided a contact of short duration between the blast and metal. An oblique blown converter with a regular converter bottom and with all tuyeres blanked except those near the surface of the metal provided similar results. There have been many modifications of tuyere arrangement to provide lower nitrogen steel. The influence of blast pressure on nitrogen, shown in Fig. 24, is related to the time of contact between blast and metal. Many methods have also been developed to reduce the nitrogen content of bottom blown converter steel. These modifications of the bessemer process permit it to approach, but not equal, the open hearth in respect to nitrogen content of the product.

The Bayer process[18] is of particular interest. Blown iron with 1.00 to 2.50 pct C is charged into the open hearth to produce steel of deep drawing quality with 0.005 pct N. This process, first desiliconizing iron in the converter, is based upon the fact that the solubility of nitrogen in iron or steel

depends upon carbon content and temperature of the bath. Another well established method for desiliconizing molten iron which does not involve a converter is ladle treatment with an oxygen lance.

Rotating Converter

Sweden has had an important part in the development of converter steel. Although thomas steel is currently being produced, the principal method for producing quality steel in Sweden is by the electric furnace process. In 1948 experimental work began in Sweden on a 3-ton rotating converter[19] blown with oxygen (Fig. 25). Rotation increased the rate of slag-metal reaction and proved so fruitful that it

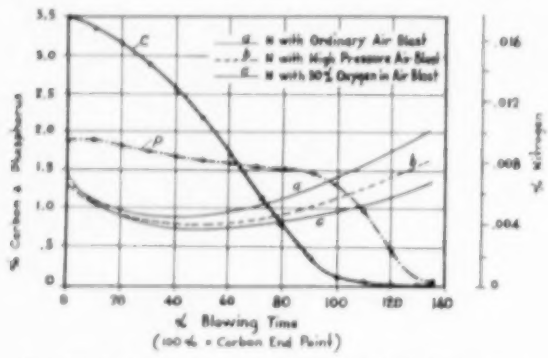

Fig. 24—Bath analysis of thomas steel with high pressure blast—Mayer & Knuppel.

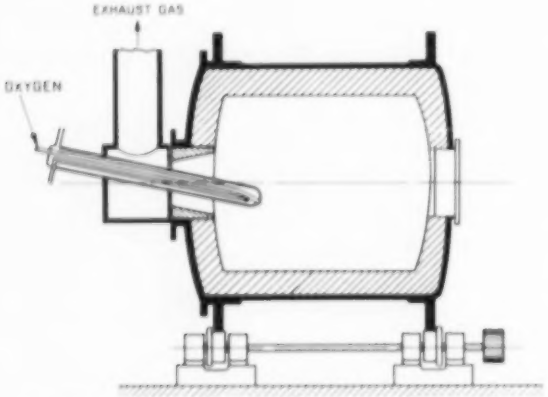

Fig. 25—The rotating converter opens the way to increased rate of slag-metal reaction.

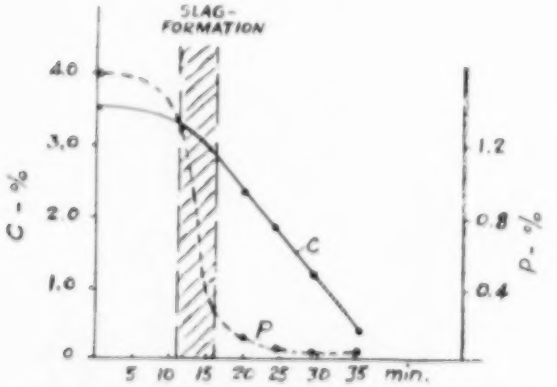

Fig. 26—Influence of slag formation on carbon and phosphorus when using pure oxygen in the rotating converter.

was continued with a 15-ton rotating converter. The influence of slag on phosphorus removal is shown in Fig. 26. With rotation, less oxygen pressure is required and the fume under certain circumstances almost completely disappeared. The bath temperature was controlled with scrap or iron ore additions and lime was used as a flux.

The nitrogen content was 0.001 to 0.003 pct with marked reduction in sulfur. The combustion of CO to CO_2 may be controlled by varying the amount of oxygen, but no attempt was made to recover the heat content of the exhaust gases. The possibility of producing a slag lining and maintaining this lining by water cooling the rotating drum was not explored. A properly controlled slag lining would reduce the refractory problem.

Oxygen-Steam and Carbon Dioxide Converter Blowing

The nitrogen content of steel may be reduced without modifying the principle of bottom blowing by enriching the blast with oxygen, adding ore, and controlling the temperature with scrap. Other methods involve the use of oxygen-steam or oxygen-carbon dioxide mixtures.

When blowing with steam or carbon dioxide, endothermic reactions occur, and the additional heat requirements are provided by using oxygen instead of air. Because of low nitrogen partial pressure low nitrogen steel is obtained. The various mixtures of gas which have been used do not appear to decrease lining life appreciably.

The use of oxygen and steam in bottom blowing has been described by J. Daubersy,[20] P. Coheur,[21, 22] and others.[23] The use of oxygen with superheated steam has received particular attention. Copper lining of tuyeres has been successfully used with basic bottoms, but it is not necessary with acid bottoms in which a refractory tuyere is employed.

The relationship between the iron content of the slag and the phosphorus content of the steel, shown in Fig. 27 indicates that lower phosphorus is associated with increased oxidizing conditions of the slag. The nitrogen content of steel blown with oxygen-steam and a lime slag, Fig. 28, shows a lower nitrogen content is the result of increased concentrations of steam.

A small amount of steel has been produced with oxygen-carbon dioxide blowing. One of the blowing mixtures employed is shown in Fig. 29, and analysis of the bath throughout the blow is shown in Fig. 30. The relationship of oxygen in the metal to the iron oxide content of slag, Fig. 31, is similar for air and oxygen enriched blows. The decomposition of car-

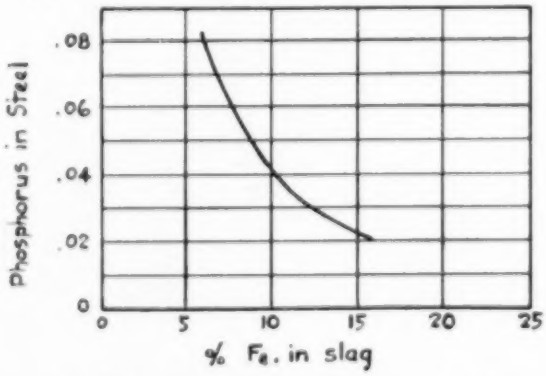

Fig. 27—Relationship of iron in slag to phosphorus in thomas steel with oxygen-steam blowing—Kosmider.

bon dioxide provides additional oxygen for removal of carbon from the melt.

Side Blown Steel Converters

At the beginning of the twentieth century the side blown converter was used principally in the foundry for the production of cast steel. Ten years ago in the U. S. there were 66 foundry converters of the type shown in Fig. 32 with a capacity of 1 to 6 tons.

It has been only within the last 15 years that the low nitrogen content of side blown converter steel has been properly recognized. In side blowing, CO is oxidized to CO_2 inside the vessel with the evolution of heat, and this increased heat is generated with less danger of over-blowing the bath. A blast pressure of 5 psi is used compared with 25 psi for bottom blow vessels.

Side blown converter experiments have been conducted with plastic converters to determine the behavior of liquids and flow of gases so that converters may be properly designed.[34] Recent experimental work with the acid side blown converter process in the U. S. has been described by Webster and Clark.[35] An experimental converter of 22-ton

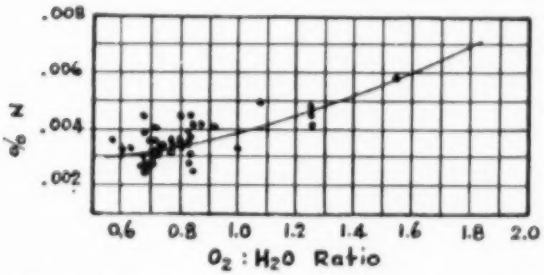

Fig. 28—Nitrogen content of oxygen-steam blown thomas steel—Kosmider.

capacity, was designed after work with a 3-ton vessel. The results indicate that steel equivalent to duplex open hearth practice could be obtained with the practice employed. Work and Webster[36] were concerned with blowing air into the bath at the beginning of the blow and on the surface of the bath near the end of the blow. During the past ten years a considerable amount of side blowing was also conducted with basic converters in Europe.

An advance in converter practice may be associated with the side blown basic converter proposed by C. E. Sims.[37] Results obtained with a ½-ton basic vessel are shown in Fig. 33. The removal of phosphorus with the carbon is of particular interest, as basic open hearth pig iron was used for the experiments and no after blow was required. There was also a decrease in sulfur. The CO_2 content of the waste gases indicates an important source of heat which was utilized to some degree in the vessel.

As a result of Sims' work a large basic lined converter was constructed and placed in operation.[38] This converter, shown in Fig. 34, is of 10-ton capacity. The steel produced contained 0.002 to 0.003 pct N, and the properties were similar to those of open hearth steel.

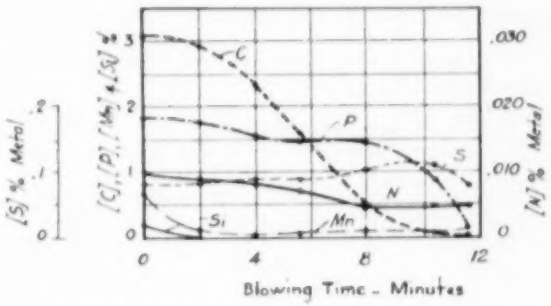

Fig. 30—Bath analysis of thomas steel with oxygen-carbon dioxide blowing—Mayer & Knuppel.

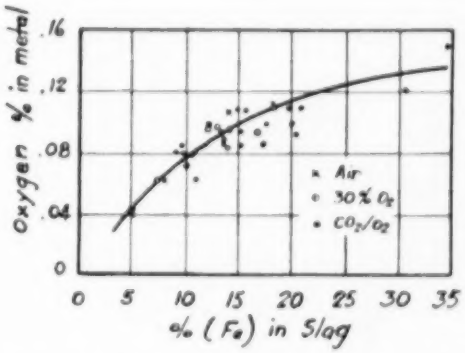

Fig. 31—Relationship of oxygen in steel to iron oxide in slag is similar for air, oxygen enriched air, and O_2-CO_2 blows—Mayer & Knuppel.

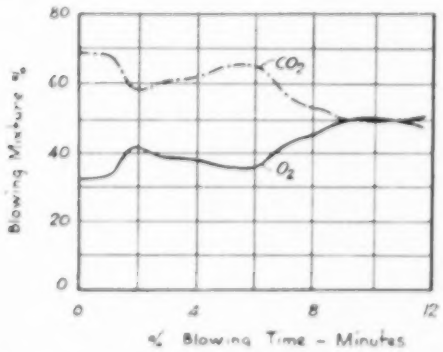

Fig. 29—Oxygen-carbon dioxide blowing mixture for thomas steel—Mayer & Knuppel.

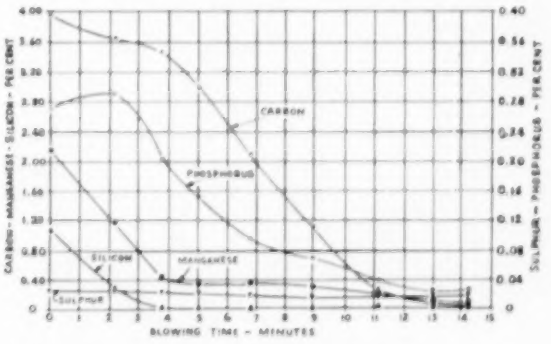

Fig. 33—Chemical analysis during a Sims basic converter blow.

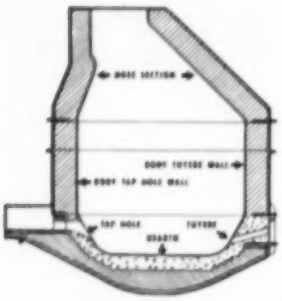

Fig. 34—Side blown 10-ton basic converter, the turbo hearth.

Oxygen Lance Surface Blown Converter

Sir Henry Bessemer in 1856 recognized the possibility of using oxygen in the converter process, but the cost was prohibitive. In recent years, however, the tonnage production of low cost oxygen has made possible its widespread use in the steel industry. The purity of oxygen used for surface blowing steel is usually 98 pct, but for low nitrogen steels it may be as high as 99.5 pct, with argon as the principal impurity. The influence of oxygen purity on the nitrogen content of steel is shown in Fig. 37.

At Linz, Austria,[1] the installation of a hot wide-strip mill and cold reducing mill created the need for low nitrogen deep-drawing steel. Open hearth scrap was in short supply, and pig iron produced at this plant was not of converter quality. In 1949, upon the suggestion of R. Durrer, an attempt was made by E. Suess, H. Trenkler, H. Hauttmann, and others to blow oxygen downward on the bath of a 2-ton converter. Later a 15-ton vessel was used. The process was successful, and in November 1952 a plant with 250,000 tons annual capacity was in operation. Compared with an open hearth, the investment and labor in Austria were 50 pct less. The refractory and flux costs were also less. A number of patents[2] have been issued in England and other countries, and the process has been called the L-D process.

During the past several years the Linz plant has produced over one million tons of steel with two 30-ton oxygen lance converters of the type shown in Fig. 35. A third converter is being installed. The Donawitz plant in Austria, placed in operation in May 1953, has a similar capacity. At the Dominion Foundries & Steel plant in Hamilton, Ontario, Canada, two 45-ton oxygen lance converters are in operation with an annual capacity of 320,000 tons of ingots. The McLouth Steel Corp., Trenton, Mich., has in operation three 50-ton oxygen lance converters. The iron analysis of typical blows is shown in Table I. It should be noted that the phosphorus content of the iron is low, for with higher levels of phosphorus a greater slag volume would be required with a reduced scrap charge. The steel produced from the iron in Table I is similar to open hearth steel.

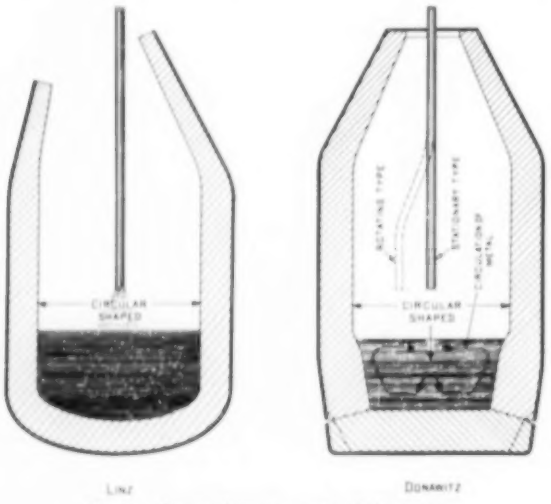

Fig. 35—Oxygen lance converter, L-D process.

Stages in the oxygen lance converter process[1] are shown in Fig. 36. The beginning, middle, and end of a blow are illustrated from left to right. A temperature of 4500°F may be obtained under the lance, and refining is concentrated in this area—the reaction area. However, the rotating motion of the bath caused by thermal diffusion, and the higher specific gravity of the refined metal, Fig. 35, causes the reaction of oxygen with the metalloids throughout the bath. The CO gas developed at the reaction area also promotes a rotating motion in the bath. As the metal is refined, the rotating action of the bath decreases, for the hottest part of the refined melt, which is under the oxygen jet, has the lowest specific gravity.

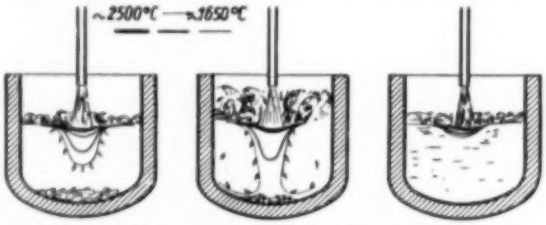

Fig. 36—Beginning, middle, and end of blow in oxygen lance converter (left to right).

The oxygen lance converter charge consists of molten pig iron, 125 lb of lime or small size limestone per ton of ingot, a small amount of spar and scale, and 15 to 20 pct scrap. The converter lining, consists of tar-dolomite brick with 250 to 300 heats obtained per lining. Dolomite consumption is 25 lb per ton of ingots.[2] About 2000 cu ft of oxygen per ton of ingot is consumed during the 20-minute blowing time. The slag shown in Table II contains only a small amount of phosphorus and, therefore, has no value as a fertilizer; about 300 lb of slag are produced per ton of ingot.

The oxygen lance converter process is used primarily for the production of low carbon steels, although medium and high carbon steels have been produced with the addition of molten iron or carbon in various forms to the blown metal. It is reported that the cost of low carbon steel produced with an oxygen lance is less than open hearth steel with similar yields, and the quality of oxygen steel is equivalent to open hearth steel. However, some factors which control the most effective use of the oxygen lance remain to be determined. Production of steel with 0.5 pct residual Mn, as shown in Fig. 38, desulfurization of the bath, and production of low phosphorus steel, as depicted in Fig. 39, are results which have been achieved and should be considered in future efforts directed toward the more effective use of the oxygen lance. Increasing the size of the oxygen lance converter and catching carbon on the way down for the higher carbon grades are considerations which remain to be developed.

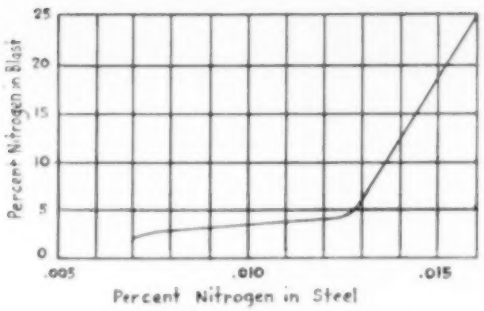

Fig. 37—Influence of nitrogen in oxygen lance blast on nitrogen content of steel—Trenkler.

Refining action may also be obtained in an open hearth[30] with an oxygen lance as determined by A. J. Kesterton in Wales. A saving in heat time was achieved with satisfactory roof life and reduction in fettling time, using a water cooled oxygen lance through the roof. In Russia[31] an open hearth is being experimentally blown with oxygen through the roof.

Summary

During the one hundred years since development of the pneumatic process, steel has provided a low cost material for the continuing industrial revolution. The first part of the present century provided few fundamental changes in steelmaking, but recent development of low cost tonnage oxygen made possible the use of the oxygen lance. Surface blowing with air and other gases and bottom blowing with oxygen-steam have also been new approaches.

The present large capacity for open hearth steel in the U. S. and the U. K. will provide a basis for the widely continued use of this process, particularly with variation of raw materials and in conjunction with oxygen lance techniques. In continental Europe production of low nitrogen steel requires different methods, and the new blowing techniques for the basic converter have been a commercial success with high phosphorus iron.

Table I. Analysis of Hot Metal For Oxygen Lance Converter

	Linz	Donawitz	Dofasco	McLouth*
C	4.0	4.0	4.4	4.2
Mn	1.8	2.75	1.3	1.5
P	0.18	0.18	0.125	0.15
S	0.04	0.04	0.025	0.025
Si	1.0	0.65	1.2	1.1

* Estimated.

Table II. Analysis* of Oxygen Lance Converter Slags

	Linz	Donawitz	Dofasco	McLouth
CaO	41	42	50	43
SiO_2	14	11	17	15
FeO	20	19	16	23
MnO	15	20	8	5
MgO	7	5	3	4.5
P_2O_5	1.5	2	1.2	—

* Al_2O_3 not shown may be 3 pct.

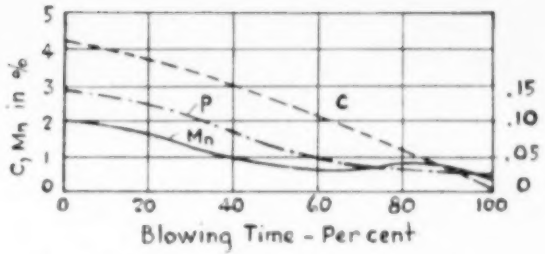

Fig. 38—C-Mn-P removal in oxygen lance converter—Trenkler.

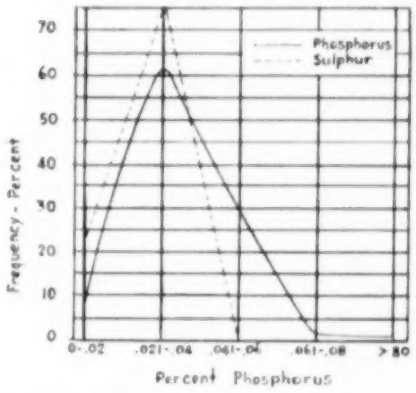

Fig. 39—P and S distribution in the oxygen lance converter process—Trenkler.

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On the Basic Pneumatic Processes of Steelmaking

by P. Coheur and H. Kosmider

THE principle of steel production by the basic pneumatic process, developed by William Kelly and Henry Bessemer, consists essentially of blowing a gaseous fluid containing oxygen into liquid pig iron. This blast refining formula, unlike hearth refining, does not require the use of any outside fuel. The required heat is liberated by the exothermic reactions between the oxygen of the blast and the elements present in the pig iron. In its conventional form, the process consists essentially of blowing atmospheric air through the metallic bath from the bottom of an acid lined converter. This process is suitable for conversion of high silicon iron of low phosphorus content. But it is not possible to eliminate phosphorus from the molten charge with an acid lining, whatever the refining process—pneumatic, open hearth, or electric.

In the blast furnace, the phosphorus in the ore is largely reduced and enters the iron; therefore, the acid processes can be used only in regions where low phosphorus iron ore deposits are found, which is the case in certain American mines. It is to be noted that the phosphorus content in steels produced from these ores by an acid process, whether in a converter or on a hearth, is nevertheless usually between 0.05 and 0.1 pct.

To refine iron obtained from ores rich in phosphorus, Sidney Gilchrist Thomas conceived and patented in 1876 a process based on Bessemer's but using a converter with a basic lining of dolomite, sintered and agglomerated with tar. He also proposed to introduce a basic flux such as burnt lime, to combine with the silica and phosphorus pentoxide formed by oxidation. Besides its direct action in the process, this basic phosphate slag has the advantage of being a valuable fertilizer, the sale of which is an important factor in the overall economy of the process.

Another point is that with a basic lining and a blast of atmospheric air, the elements whose oxidation liberates heat must be present in the pig iron within a fairly narrow range of concentration. This range narrows as the size of the converter decreases and as the amount of sensible heat in the liquid pig iron falls.

The basic converter process, called *thomas* in Europe and *basic bessemer* in the U. S., enables the utilization of the large deposits of phosphorus-rich ores in Lorraine and Sweden. These ores yield a pig iron of exactly the required analysis, which is the reason why the thomas process had led to the great development of steel production in continental Europe.

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The Basic Bessemer Process in Its Present State of Development

Like hearth refining, the conventional basic bessemer process has its advantages and drawbacks. On the credit side, there is the speed and the simplicity of the operation, and the possibility of producing steel with a very low carbon content. On the debit side, the nitrogen and phosphorus contents of bessemer steels are somewhat higher than normal open hearth steels (Table I). But this is only the result of the higher phosphorus content of the iron and not the result of the process.

There is not doubt whatever that the steel produced by the conventional basic bessemer process is

Table I. Pig Iron and Steel Compositions for the Basic Bessemer (Thomas) and Open Hearth Processes

Process	Pig Iron					Steel (Ladle Analysis)		
	Pct C	Pct P	Pct S	Pct Mn	Pct Si	Pct N	Pct P	Pct S
Basic Bessemer	3.60 3.90	1.50 2.10	0.040 0.080	0.4 1.2	0.20 0.60	0.0090 0.0120	 ~0.045	 ~0.035
Open Hearth†	4.10 4.40	0.10 0.90	<0.050	0.4 2.0	0.50 1.50	0.0030 0.0060	0.010 0.030	0.025 0.040

* Belgian and Luxembourg steel plants.
† *The Making, Shaping and Treating of Steel*, 6th edition, 1951, p. 284.

excellent for general structural steels, reinforcing concrete rods, screw stock, magnetic sheet (transformer sheet) and wire for certain application. It even has properties which are specially valuable for such application as rails, plates, and spring wire. Thus, for numerous applications, there is no major advantage in modifying the steels obtained in the converter by the conventional method. However, for some applications requiring a high degree of ductility at room temperature, such as for cold rolling, drawing, etc., the usual rimmed basic bessemer steel is handicapped by its nitrogen and phosphorus content. This is why new manufacturing processes have been developed over the last half-century.

Table II. Mean Nitrogen, Phosphorus, and Sulfur Content of Converter Steels

Process	Pct N		Pct P		Pct S	
	Mean	σ*	Mean	σ*	Mean	σ*
Atmospheric air	0.0090 to 0.0120	0.0025	0.045	0.012	0.035	0.007
Enriched air with:						
1) Scrap	0.0080	0.0015	0.045	0.012	0.035	0.007
2) Scrap, ore, limestone	0.0060	0.0012	0.035	0.007	0.025	0.005
3) Ore, limestone	0.0050	0.0010	0.025	0.006	0.020	0.005
O. V.	0.0025	0.0005	0.020	0.006	0.020	0.005

* Standard Deviation.

Bottom Blowing

By carefully controlling the standard process, steels with relatively low average phosphorus and nitrogen contents are currently produced. For example, in the Belgian-Luxembourg plants, the figures are: 0.007 to 0.012 pct N and 0.04 to 0.05 pct P.

Fig. 1 illustrates the standard frequency curve for nitrogen. This curve was drawn from more than 35,000 blows with atmospheric air. The mean value is 0.0095 pct and the standard deviation is around 0.0012 pct. To reduce the nitrogen content of steel further, without basically modifying the principle of bottom blowing, special methods must be utilized. They are at present used on an industrial scale with great success and are likely to give a new impulse to the development of blast refining methods in the fields where it is necessary to reduce the nitrogen content, namely the flat products for applications requiring a high ductility.

Modified basic converter processes consist essentially of reducing the partial pressure of nitrogen and the quantity of this element blown while maintaining the temperature of the metallic bath on the low side. They are based on the fact that the nitrogen content of a steel is related to its partial pressure in the gas blown through the metal.[11] This relationship was discovered by J. H. Andrew in 1911 and put into mathematical formulas by C. B. Sawyer in 1923.[12] It indicates that the blast should be diluted with a gas free of nitrogen, which, in fact, is what Eldred[4] proposed 50 years ago.

The blast can also be enriched in oxygen, and the resulting increase in bath temperature neutralized by supplementary additions of scrap, ore, or limestone. Finally, the air blast can be cut off and replaced with a mixture of oxygen and a gas free of nitrogen.

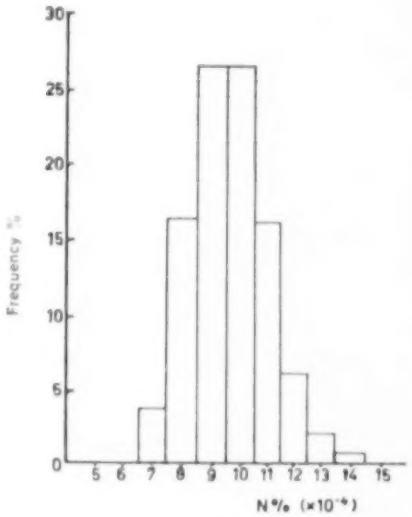

Fig. 1—Frequency curve for the nitrogen content of steels blown with atmospheric air.

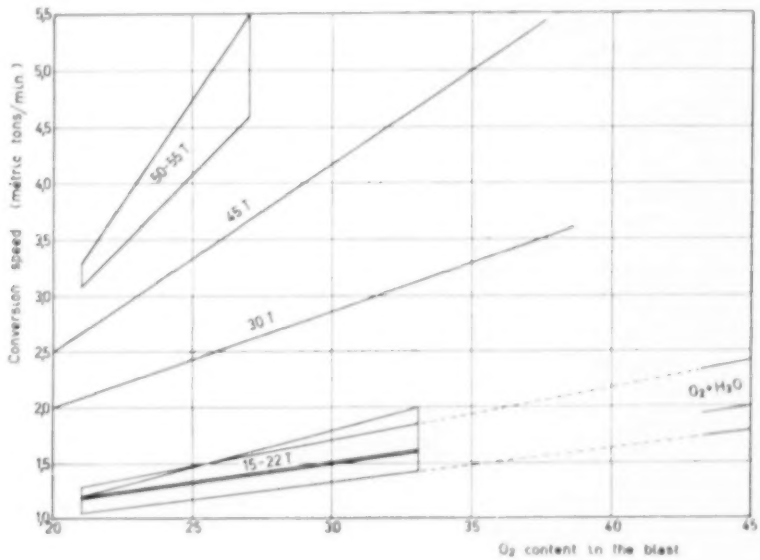

Fig. 2—Relation between the speed of conversion and the oxygen content of the blast in converters ranging in capacity from 15 to 55 tons.

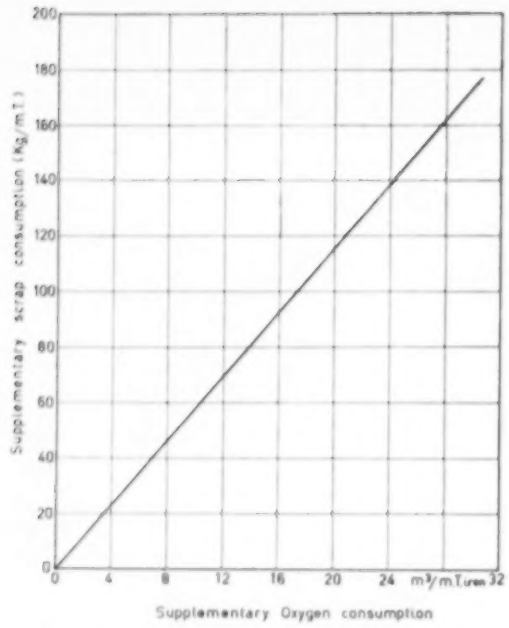

Fig. 3—Relation between oxygen enrichment of air blow and scrap consumption in a basic (thomas) converter.

Applied industrially in Belgium, Luxembourg, and Germany, some of these various methods of blowing have given the analytical results shown by Table II.[1,10] It will be seen that they enable the nitrogen content of steel to be substantially reduced. Note particularly the results with oxygen enriched blast with additions of ore and limestone, and also the OV (oxygen plus steam process). The latter yields steel with lower nitrogen contents than current open hearth steels. Furthermore, when blowing with oxygen plus steam, the brown fume problem disappears, avoiding the necessity of gas-cleaning equipment.

Whatever the blast used, the phosphorus content of the steel can be reduced by making a second slag in the converter. With such a double slag process, steel containing about 0.02 pct P and 0.02 pct S can be produced. Thus, it is possible to produce converter steels having the nitrogen phosphorus, and sulfur, very close to, and even lower than open hearth steel.

From the point of view of economics, the use of oxygen in the blast permits an increase in the rate of refining and hence the output per converter allows greater quantities of scrap to be charged, and enables types of pig iron to be handled which are difficult to blow with conventional methods.

Concerning the rate of refining, Fig. 2 shows the linear relation between the rate of conversion expressed in tons of converted iron per min, and the oxygen enrichment of the blast. For example, with a 30-ton converter, the rate of refining with atmospheric air is on the order of 2 tons per min, and with an oxygen enrichment of 30 pct it is on the order of 2.8 tons. Such an increase of the rate raises by 20 pct the production of converters.

Concerning the quantity of scrap charged in the converter, Fig. 3 indicates an increase of scrap consumed in terms of the supplementary consumption of oxygen per ton. The quantity of scrap may be varied from zero to 20 pct of the pig iron, or even to 25 pct with high capacity converters when using oxygen enriched air.

Concerning the thermogenic power of pig iron, Table III shows the thermal equivalents of 0.1 pct P, Si, Mn, and C when the blast is atmospheric air, or air enriched to 30 to 40 pct O_2. This table is based on the work of Senfter, Schnurch, and Guthmann,[9] assuming that the amount of lime is twice that required by the chemical reactions. The converters hold from 15 to 20 metric tons, and the temperature of the pig iron is 1250°C (2282°F) and the steel 1625°C (2957°F).

Table III. Thermogenic Power of Major Elements in Pig Iron When Blown with Air and Oxygen Enriched Air

0.1 Pct	Pct O_2 in Blow	Heat Produced, Kcal per Metric Ton	Scrap, Kg per Ton	Lime, Kg per Ton
Phosphorus	21	1682	5.5	—
	30	2427	8.0	5.5
	40	2849	9.3	—
Silicon	21	1815	6.0	—
	30	2304	7.6	8.0
	40	2601	8.5	—
Manganese	21	979	3.2	—
	30	1196	3.7	—
	40	1196	3.9	—
Carbon	21	985	3.2	—
	30	1710	5.6	—
	40	2138	7.0	—

Table III permits a comparison between the heat-producing capacities of typical basic bessemer and open hearth pig irons whose composition is given in Table I. For simplicity, median values are considered, and on the basis of experience it is assumed that one ton of basic converter pig iron having the given analysis can consume 4.5 pct scrap and requires 135 kg of lime when blown with air.

On the basis of the data given in Table III, open hearth pig iron has a theoretical heat-producing capacity sufficient for blowing with atmospheric air. Table IV shows that 100 kg of lime per ton would be required. In order to obtain the same final temperature as when operating with basic bessemer pig iron,

Table IV. Operating Data for Bottom Blown Basic Bessemer and Open Hearth Grades of Pig Iron

	Pig Iron Composition					Lime, Kg per Ton	Scrap Added, Kg per Ton		
	Pct C	Pct P	Pct S	Pct Mn	Pct Si		21 Pct O_2	30 Pct O_2	40 pct O_2
Basic Bessemer	3.7	1.80	0.060	0.80	0.40	135	45	200	290
Open Hearth	4.2	0.50	0.040	1.20	1.00	100	35	180	270
	4.2	0.20	0.040	2.00	0.75	65	30	165	250
E. B. K.* Hamborn	3.8	0.15	0.030	2.80	0.70	30	‡	—	—
K. N. W.† Haspe	4.3	0.60	0.035	2.10	0.75	90	—	85§	—
R. I. Oberhausen	4.2	0.12	0.035	1.75	0.75	100	—	80**	—

* W. Eichholz, G. Behrendt and T. Kootz, *Stahl und Eisen*, 1940, vol. 60, p. 61.
† H. Kosmider, H. Neuhaus and A. Weyel: *Stahl und Eisen*, 1954, vol. 74, p. 1473.
‡ H. Rickmann: *Stahl und Eisen*, 1954, vol. 74, p. 1484.
§ Temperature of the pig iron: 1180°C (2156°F).
** 1 kg ore = 2 kg scrap. Prerefined iron: T° of the iron = 1310°C (2390°F).

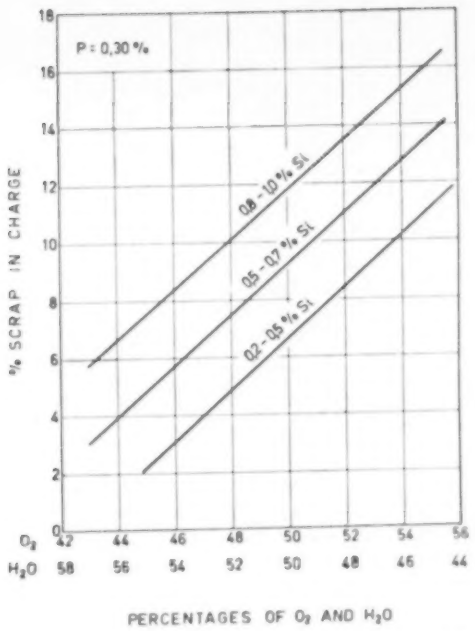

Fig. 4—Relation between the quantity of scrap used and the O_2:H_2O ratio for three levels of silicon in iron containing 0.3 pct P.

35 kg of scrap per ton is required. With air enriched to 30 pct O_2, the quantity of scrap rises to 18 pct, and with air containing 40 pct O_2 the scrap requirements are 27 pct. Note that an open hearth pig iron with less phosphorus and silicon can also, in principle, be converted without thermal difficulty.

These theoretical reflections have been confirmed experimentally at three plants. The first was in 1939 by Eichholz, Behrendt, and Kootz at the Thyssen Works at Hamborn, Germany.[19] Using an air blast these specialists refined without difficulty 6000 tons of pig iron of the analysis shown in Table IV.

There were the experiments carried out in 1954 by the authors and those in collaboration with Neuhaus and Weyel at the Klöckner Hüttenwerk Haspe in Germany.[20] The authors used an oxygen enriched blast and a standard open hearth iron. The amount of scrap added to cool the charge was lower than had been calculated, partly because the temperature of the pig iron was definitely lower than assumed in the calculations, which in fact, corresponds to the temperatures obtained in the Liège Belguim steelworks.

Finally there were the experiments carried out in 1954 at Oberhausen, Germany,[21] again with a standard open hearth pig iron and oxygen enriched blast. This enrichment was not kept constant throughout the blow, but was increased progressively, finally attaining 35 to 37 pct O_2.

The chemical analysis of the resulting steels is remarkable. At Oberhausen the steelmakers by cooling the bath with ore obtained a steel containing an average of 0.0062 pct N, 0.023 pct P, and 0.019 pct S.

Recently one of the authors in collaboration with Weyel with the oxygen plus steam mixture converted pig irons of the following analysis: 4.0 to 4.5 pct C, 0.8 to 1.2 pct Mn, 0.17 to 0.53 pct P, 0.36 to 0.97 pct Si, and 0.03 to 0.04 pct S. The experiments were on about 20 blows of 22 tons each. The volumetric concentration of oxygen in the mixture was on the order of 45 pct, and its consumption was 75 cu m per ton. The quantity of lime charged was 7.2 pct, and the scrap consumed was some 3.4 pct.

The curves in Fig. 4 show the quantity of scrap used according to the ratio O_2:H_2O. These curves refer to three levels of silicon in pig iron and a phosphorus concentration of 0.3 pct. The size of the converter was 25 metric tons, and the time of conversion was 7½ min. The iron yield was about 87.2 pct, and the resulting steel, obtained without a double slag, had a temperature of 3000°F. Its chemical analysis was 0.046 pct C, 0.25 Mn, 0.019 pct P, 0.016 pct S, and 0.0035 pct N.

It is the authors' opinion that all of these results are extremely important, for they can be applied in two directions: first by extending blast refining to open hearth pig irons, for which it was not originally intended. Second by modifying the conditions for the production of pig iron in the blast furnace, it is possible to produce, if necessary, pig irons of smaller chemical heat producing capacity than under normal operating conditions. From the heat balance viewpoint, there would be no point in returning basic converter slag to the blast furnace in order to increase the phosphorus concentration in the iron.

Top Blowing

The principle of blowing with enriched air or oxygen plus steam is not new, for it was foreseen by Bessemer himself in his patents practically 100 years ago.[22] It is interesting to point out that Bessemer had ideas not only about the nature of the blast, but also about the way to inject it, for he conceived the possibility of blowing from the top of the converter as well as through the bottom. Fig. 5 is taken from one of his patents.

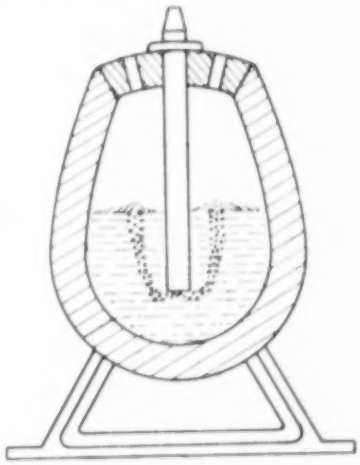

Fig. 5—Top blowing as proposed by Bessemer.

This variation has been studied in recent years, mainly in Austria, and has given remarkable results.[23-25] At present the process is used only on low phosphorus pig iron because the slag, to some extent, intercepts the blast of oxygen, and with high phosphorus iron, it is difficult to detect the end of refining so that the results and the operation are somewhat irregular. The process, using a blast of 99 pct oxygen is known as the L-D process, meaning *Linzer Düsen Verfahren*. It should be noted that blowing by this arrangement lasts slightly longer than with bottom blowing. Also the quantity of scrap which must be used is on the order of 20 to 25 pct, and it is difficult to keep down. This may or may not be an advantage, depending on local circumstances.

Table V. Comparison of Chemical of Analysis of Steels Produced by Various Converter Techniques

Processes	Pig Iron Composition					Steel Ladle Analysis		
	Pct C	Pct P	Pct S	Pct Mn	Pct Si	Pct P	Pct S	Pct N_2
Linz*	4.0	0.20	0.080	1.80	1.00	0.022	0.020	0.0040
Donawitz†	4.0	0.20	0.030	2.80	0.70	<0.050	0.025	0.0020
B. Kalling‡	3.3	1.60	0.060	0.70	0.30	0.035	0.023	0.0020
						0.025	0.020	0.0030
Turbo hearth§ **	4.0	0.30	0.035	1.95	1.10	0.010	0.022	0.0025
O. V.	3.7	1.80	0.060	0.80	0.40	0.020	0.020	0.0022
Open Hearth	4.0	0.25	0.040	1.70	1.00	0.015	0.025	0.0040

* *One Year of Application of L. D. Oxygen Refining Process*, 1954, p. 19. Austria. Voest.
† O. Cuscoleca: JOURNAL OF METALS, 1954, vol. 6, p. 817.
‡ B. Kalling: *Revue Universelle des Mines*, 1953, p. 620.
§ C. E. Sims and F. L. Toy: JOURNAL OF METALS, 1950, vol. 2, p. 694.
** C. D. King: JOURNAL OF METALS, 1954, vol. 6, p. 462.

Instead of top-blowing in a stationary converter, Kalling[20] has proposed the use of a rotating converter or furnace (See Fig. 25, p. 750). This ensures better contact between the slag and the metal and can handle high phosphorus iron. The process has not been developed beyond the experimental stage, but the results seem promising, for Kalling has obtained a steel of analysis similar to that from the OV or L-D processes, (Table V).

Side Blowing

A third possible way of blowing also proposed by Bessemer[17] is side blowing (see Fig. 13, p. 747). The method is used in certain small acid converters in steel foundries (Tropenas process). It has been studied in the case of basic linings at the Mannes-

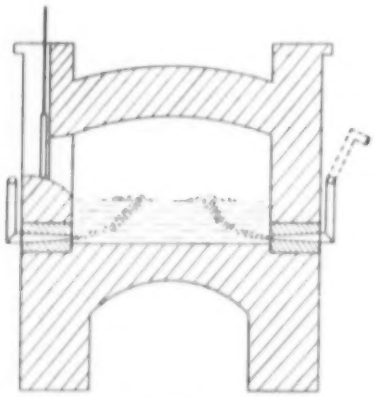

Fig. 6—Injection of an oxidizing gas mixture into a hearth furnace as proposed by Bessemer.

mann Röhrenwerke in Germany (MA process), but as far as is known,[21, 22] the process has not been further used because the life of the tuyeres is very short, the lining is strongly attacked, and the iron yield of the process is reduced.

Another form of this method of blowing is provided by experiments carried out in the U. S. with a converter called the *Turbo-Hearth* (see Fig. 34, p. 752). These experiments[20, 23, 24] are being continued on a large scale, with a basic converter of 10 ton capacity. It appears that the results are encouraging, for a steel is obtained, from open hearth iron, that is near the composition obtained by the OV, L-D, or Kalling processes. This is not surprising, because in the three cases, the iron is blast refined by the basic conversion principle of injecting an oxygenated gas into liquid pig iron, (Table V).

Blowing into a Hearth Furnace

The bessemer-martin (bessemer-open hearth) process is mentioned because Bessemer did not restrict himself to a study of iron refining in a converter, but also considered refining in a hearth furnace, and in particular in reverbratory furnaces. This is shown by Fig. 6 and Fig. 7, which are taken from his patent of Dec. 7, 1855. This proposal has been adopted in recent years following the development of production techniques for low cost, tonnage oxygen. Actually such processes involving the injection of oxygen into open hearth furnaces ought to be named after their inventor, Bessemer.

Bottom Blowing with Additional Oxygen Lancing

Bottom blowing presents the special advantage of ensuring, during the whole operation, a vigorous stirring of the charge, and consequently, a narrow contact between the slag and the metallic bath; the iron yield of the operation is most satisfactory, and the rate of conversion is high. However, only a limited amount of scrap may be consumed.

The quantity of scrap melted in the bottom-blown process depends on the temperature, the analysis of the hot metal, and especially on the temperature and nature of the blast.

During the oxidiation process, the waste gases have a high calorific value, for they contain from 30 to 40 pct CO when blowing with air; 50 to 60 pct CO with 35 pct O_2 in the blast, and 90 pct CO + H_2 when blowing with the oxygen-steam mixture.

Bansen[25] proposed the burning of the waste gases with air. The authors have proposed and industrially investigated the combustion with oxygen in order to modify the heat balance and consume more scrap. Theoretically, every cu m of oxygen combines with carbon monoxide or hydrogen and supplies 6000 calories which, if assigned to the metallic bath and used to heat the gases 100°C higher, would enable about 14 kg of scrap to be smelted.

Practically, the authors have found that every cu m of oxygen enabled the consumption of from 10 to 12 kg of scrap, when oxygen is injected into 17-ton converters at a rate of 20 cu m per min.

In these experiments, the blast pressure was chosen so that the oxygen did not come in contact with the metallic bath and only burned the carbon monoxide or hydrogen of the gas. The authors increased by 70 kg per ton of iron the quantity of scrap consumed.

Furthermore, oxygen blown by the lance does not come into contact with the liquid metal and consequently it does not produce brown fumes.

Mechanical Properties

The question now arises as to whether the steel made by one or another of these pneumatic processes has mechanical properties comparable with those of open hearth steel. To answer this question many experiments have been made in Europe and America and were the object of numerous publications.[38, 42, 46, 51, 55-62]

According to American, Austrian, German, French, and Swedish steelmakers, the properties of steel produced with the new pneumatic processes are equal to, if not better than, those of open hearth steels. Thus, according to Sims and Troy,[51] steels obtained with the Turbo-Hearth at the South Chicago Works of U. S. Steel Corp. have standard mechanical properties, with bending elastic properties, aging characteristics, and transition temperatures similar to those of open hearth steels of the same composition.

Hauttmann,[46-47, 59] who has specially studied the question, has shown that the steels produced at Linz by top blowing have the standard mechanical properties, solid ductility, and toughness. In addition, the steels exhibited a resistance to corrosion in general and to intergranular corrosion in particular, resistance to aging, and a fatigue strength as well as welding properties that are similar, if not superior, to those of open hearth steels of the same composition.

Cuscoleca[42] has examined the properties of L-D steels produced at Donawitz, Austria, and has come to the same conclusion as Hauttmann. He emphasized that the new steels are less susceptible to brittle fracture than open hearth steels, have better welding characteristics.

In Belgium, Luxembourg, and Germany many tests have also been undertaken to check the ductility and weldability of the steel. It was found that, for chemical analyses which are equal or close, basic converter steel is as good as open hearth steel. There thus appears to be sufficient experimental evidence to show that steel produced by these two differing processes—pneumatic and conventional open hearth—are mechanically similar.

Fig. 7—Bessemer's proposal for the injection of an oxidizing gas mixture into an alternate design of hearth furnace.

Conclusions

For European countries, which have to base their steelmaking on high phosphorus ores, large quantities of basic bessemer steel have been produced and used for many years.

Extensive application in many fields, such as bridges, rails, railroad cars, and structural construction, has been made and is made every day with the most significant success.

With these processes—whether bottom, top, or side blown—the authors have shown that it is now possible to reach the special field of application requiring a very high ductility at room temperature. The steel produced is at least as good as open hearth steel.

From an economic point of view, the new methods of blowing permit a better gearing of steel plant to market and raw material conditions:

a) Those in charge of the separate divisions of a steel plant can regulate the relative quantities of pig iron, scrap, and ore consumed and converted into steel.

b) Those in charge of the steel plant as a whole can select the most satisfactory burden for blast furnaces.

c) Finally, iron normally sent to open hearth furnaces can be refined in converters.

All these results are likely to give a new impulse to the development of the basic pneumatic process. In fact, they already have done so, if consideration is taken of the new steel plants which have recently been built or are under construction throughout the world.

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The L-D Process In Austria

Based on an article

in Progrés Réalisés en 1955 dans la Sidérurgie, published in English and French by the United Nations, Economic Commission for Europe, Geneva, Switzerland, February, 1956.

by

B. Matuschka

The Economic Commission for Europe (ECE) is one of three regional economic commissions organized by the United Nations. It has as participating members, in addition to the U. S., most of the countries of eastern and western Europe. One of the sub-bodies of ECE is the Steel Committee which meets periodically to consider production and consumption problems. As a part of its activity, an annual review on European technological developments is published.

In order to keep AIME members informed on the latest trends in the European steel industry, the JOURNAL OF METALS is publishing in June and July excerpts from several articles in *Progrés Réalisés en 1955 dans la Sidérurgie* (Advances in Steel Technology in 1955).

THE process for the production of steel with the use of an oxygen lance in a converter-like vessel was developed in Austria in 1951 at the plants of the Vereinigten Österreichischen Eisen- und Stahlwerke (VOEST) at Linz and the Österreichische Alpine-Montangesellschaft at Donawitz. It has become known as the Linzer Düsen Verfahren, or L-D process, and has shown a considerable development during the last few years. This is evident from Table I, which shows production of steel according to the process in Austria. During the year 1955 the quantity of steel produced by the L-D process was equal to the entire Austrian steel production in 1937, and today the Austrian industry, which previously had used only open hearth and electric furnace steel, employs steel from the L-D process with results identical to open hearth grades.

Austrian producers claim that the quality of L-D steel is actually superior to other grades, for by using 98 to 99 pct O_2, L-D steel averages between 0.0015 and 0.0025 pct N. Open hearth grades, on the other hand, according to Bading, vary between 0.004 and 0.007 pct N, while bessemer and thomas steels using a straight air blow contain from 0.010 to 0.20 pct N. However, recent improvements in the pneumatic converter process have permitted the reduction of nitrogen content of converter steels to lower levels. But the quality of steel is dependent also on the oxygen content and the state of the contained oxygen. In the L-D process the oxygen reacts directly with iron, carbon, and other elements so as to minimize over-oxidation of the bath.

According to Richard, the figures for the temperature increase due to the oxidation of the various elements in the refining of Austrian pig iron either with air or pure oxygen are as shown on Table II.

Low phosphorus Austrian pig iron, in spite of its high manganese, is not treated satisfactorily by air blowing in a converter, for the temperature rise of 311°C is insufficient, since the fusion point of pure iron surpasses that of the Fe-C eutectic by 400°C. For European thomas pig iron there is, however, sufficient phosphorus to raise the temperature of the converter bath above this 400° minimum with air blowing, and Table III shows the increase in temperature attributable to each element when air blowing thomas pig iron.

Tables II and III show that in the air blowing of either Austrian pig iron or European thomas pig iron only 4 to 8 pct of the increase of temperature is due to the combustion of the carbon. But with the L-D the oxidation of carbon is responsible for at least 20 pct of the temperature rise. And if it is assumed that the concentration of oxygen causes a major portion of the carbon to be oxidized to CO_2 rather than to CO, then the elevation of the temperature due to the carbon alone represents as much as 30 pct of the total temperature rise in the L-D process.

In Table II it can be seen that the combustion of carbon plays a predominant role in the temperature difference between the air blowing and the L-D techniques. Of the 184° difference, the combustion of carbon accounts for 76° or 40 pct. If the carbon is burned to CO_2 in the L-D process then there will be an additional increase in temperature of about 50° to 545°C; so, carbon could be responsible for more than half of the difference in the operating temperatures between the two techniques.

Table I. Austrian Steel Production by Process, 1951 to 1955

Year	L-D Process		Open-Hearth		Electric Furnace		Total Steel in 1000 Metric Tons
	1000 Metric Tons	Pct Total	1000 Metric Tons	Pct Total	1000 Metric Tons	Pct Total	
1951	1.3	0.1	800	77.9	226	22	1.027
1952	6.0	0.6	811	77.4	239	22	1.056
1953	332	26	750	59	201	15	1.283
1954	593	36	804	49	225	15	1.653
1955	657	37	856	47	295	16	1.824

Table II. Temperature Increase in the Conversion of Austrian Pig Iron

Element	Reduced		Combustion in Air		Combustion in O_2	
	From Pct	To Pct	Temperature Increase in °C per Pct Element Oxidized	Total Temperature Increase in °C	Temperature Increase in °C per Pct Element Oxidized	Total Temperature Increase in °C
C	4	0.1	6	24	25	100
Si	0.7	0	190	133	235	161
Mn	2.2	0.4	46	86	65	122
P	0.13	0.03	120	12	175	18
Fe	2 pct oxidized		28	56	47	94
				311		495

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The question is whether this increase in the activity of the carbon in the L-D technique produces tangible operating results. Extensive experiments made by the Max-Planck-Institut in Düsseldorf, Germany, have given evidence to a fact well known to metallurgists, namely that such factors as a delay in boiling and surface tension play an important role in the course of decarburization, particularly at the beginning. The activity of carbon, A', must be as great as possible for these effects to be overcome and for the combustion to commence early and continue uniformly to equilibrium. Toward the end of decarburization, the deoxidation observed by Hauttmann starts from the point of contact of the oxygen, and this reverse reaction tends to prevent overoxidation.

With respect to the activity of the carbon, A', Chipman has established the following relationship:

$$\text{Equilibrium constant, } K' = \frac{\rho CO}{A' \times A''}$$

with the effect of temperature upon this constant as follows:

$$\log K' = \frac{2.065}{T} + 1.643.$$

Under these conditions the activity of the carbon increases as the temperature increases. It can be deduced, according to H. Schenck in Germany, that the speed of decarburization is given by the relationship

$$\frac{d\,\Sigma C}{dt} = K(FeO) \cdot (\Sigma C) - K_2 \cdot \rho CO.$$

This indicates that the rate of reaction should be slow at the end of the process in order that the quantity of FeO in the bath may be minimized. The curves in Fig. 1 show the rate of reaction in the thomas and the L-D processes during the course of decarburization. The rate of reaction in the thomas process is low initially, increasing to a maximum at the end of decarburization, resulting in a high oxygen content of the bath. The rate of reaction of the L-D process is more rapid during the early phases, reaching a maximum after 12 to 14 min, and thereafter decreasing to a low value. This has the effect of minimizing the oxygen content of the bath.

Table III. Temperature Increase in the Air-Conversion of European Thomas Pig Iron

Element	Reduced		Temperature Increase in °C per Pct Element Oxidized	Total Temperature Increase in °C
	From Pct	To Pct		
C	3.5	0.1	6	20.4
Si	0.5	0	190	95.0
Mn	1.0	0.4	46	27.0
P	2.2	0.03	120	264.0
Fe	2 pct oxidized		28	56
				463

According to Chipman, the elevation of the working temperature causes an increase in the coefficient of activation of carbon and supresses a decrease in boiling, which results in an increase in the speed of refining without increasing the FeO content of the bath. This intensification of the refining also is accompanied by excellent degassing and by a strong elimination of slag inclusions, which explains the low degree of segregation of L-D ingots.

As already noted, the combustion of carbon in pure oxygen results in an elevation of the temperature early in the process. The increase of heat necessitates a cooling through the addition of from 20 to 30 pct scrap. However, the cooling does not produce its full effect until the temperature is sufficiently raised, that is, at the time when the refining action has become intense.

It has been demonstrated on an industrial scale that it is neither necessary nor desirable to maintain such elevated temperatures until the end of refining. It is essential only to attain them rapidly to cause a decarburization and dephosphorization as early as possible. Thus, the lining of the vessel is not subjected to abnormal working conditions. The length of the refining is not less than that of the acid or basic bessemer process.

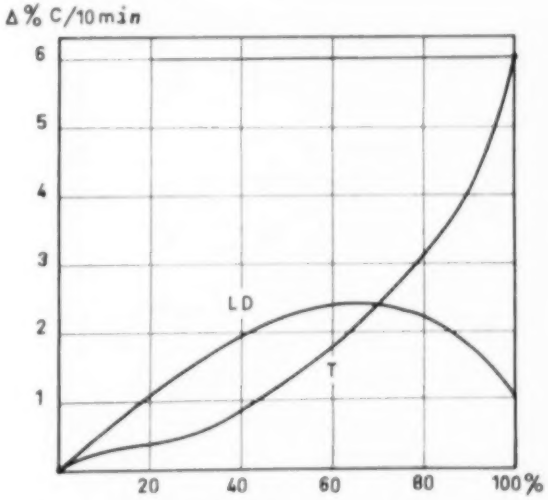


Fig. 1—The rate of decarburization in the thomas converter (curve T) increases to the end of the reaction, while in the L-D oxygen lance process (curve L-D) it reaches a maximum after 12 to 14 min and then decreases.

If it is necessary to obtain heats with a particular composition, the temperature at the end of the heat is sufficiently high so that additions of carbon or alloying elements can be made before casting. However, it is generally not necessary to add ferromanganese to deoxidize the heats.

A combination of the L-D process with the open hearth as a duplex operation is unnecessary because of the high quality of the steel obtainable by the L-D process, and such an operation results only in an increase of production costs.

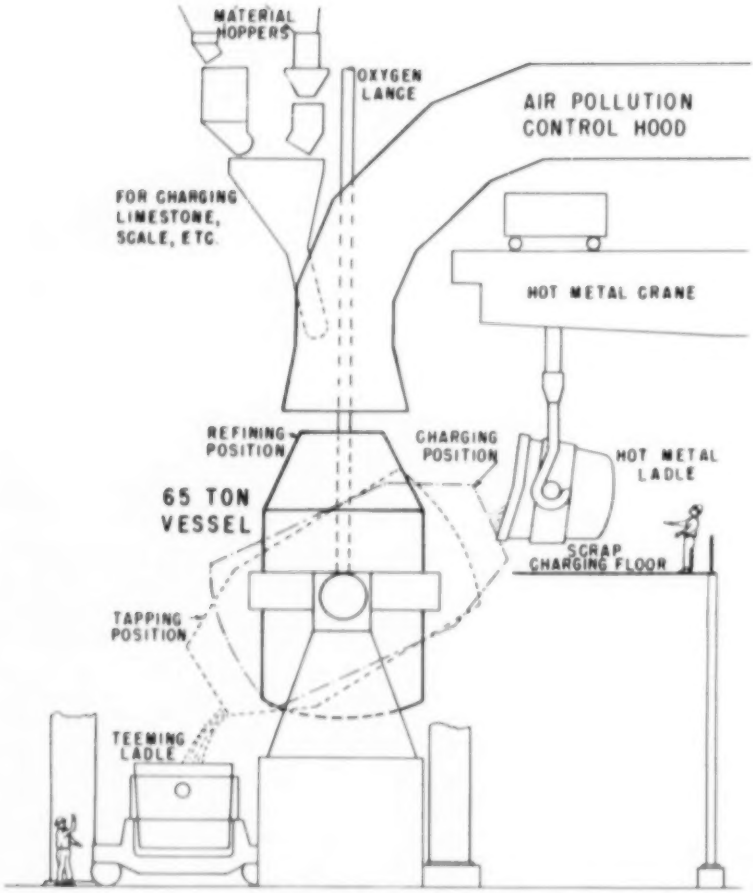
The improvement in the converting of iron, resulting from the rapid activation of carbon, and from the early combustion of the carbon and the phosphorus, constitutes a characteristic peculiar to the L-D process.

The thomas process as recently improved by enriching the blow with oxygen and using special fluxes, or by using oxygen and carbon dioxide or oxygen and steam mixtures, does not present the same favorable metallurgical conditions and lacks the characteristics that have been described for the L-D oxygen lance process.

Second and Third Oxygen Converter Plants in U. S. Under Construction

Following the successful operation of three 50-ton oxygen lance converters at McLouth Steel Corp. at Trenton, Mich., an oxygen converter plant of 300,000 ton capacity is being constructed at Jones & Laughlin Steel Corp.'s Aliquippa, Pa. plant and is expected to be in operation early in 1957. Kaiser Engineers, the U.S. Licensor of the process, is also installing two 65-ton oxygen converters at Kaiser Steel Corp.'s Fontana, Calif. plant. Construction will get underway at once, and the plant is scheduled for operation in 1958, raising the production of finished steel products by some half million tons.

L-D PROCESS



OXYGEN STEELMAKING UNIT
KAISER STEEL FONTANA PLANT

Produces: low carbon steel of low N and O content. Slag inclusions are few, and segregation is less.

Requires: low phosphorus pig iron and some 25 pct scrap in charge.

Advantages: bessemer production speed resulting in open hearth quality steel; moderate capital costs and low operating costs.

Disadvantages: speed of operation prevents catching carbon on way down; hence, without recarburization produces only low carbon steel. Process makes heavy volume of fumes.

Future Trends of the Pneumatic Process

by J. E. Stukel

IT is a recognized fact that the bessemer process has been diminishing in importance in the U. S., and there was every reason to believe that this decline would continue. However, two recent European developments in the pneumatic process have altered this picture. The aim of both of these is to keep the nitrogen content of the resulting steel at or lower than open hearth values (0.004 pct N). These low nitrogen values are achieved by using oxygen rather than air, and the primary difference between the two techniques is the manner in which the oxygen is introduced into the metal bath.

In the L-D (Austrian, oxygen lance) process, the bottom is sealed off, and oxygen is introduced to the metal by means of a vertically suspended, water cooled lance. At the oxygen-metal reaction zone the temperature exceeds 4000°F, and the nitrogen pick-up is rapid; therefore, oxygen 99.5 pct pure must be used to maintain a low nitrogen in the bath. Furthermore, this high reaction temperature volatilizes some iron and manganese (30 lb per ton of ingot), and the fumes are extremely voluminous. In order to avoid excessive air pollution expensive gas cleaning equipment is necessary.

In the OV process, a conventional type converter is used, blowing with a mixture of oxygen and steam. A higher oxygen concentration in the blast allows a greater scrap consumption; however, this must be balanced against a higher refractory consumption. Generally, a mixture of equal parts of oxygen and steam, having the same thermogenic power as air, achieves optimum results. In basic-lined converters, the steam must be superheated to prevent condensation in the tuyeres which greatly reduces refractory life. Condensation does not appear to affect the acid bottom life. Since the temperature at the point of contact between the molten metal and the oxygen-steam blast is about the same as for an air blow, there is no additional fume formation. Furthermore, there is no slopping; the flame is sharp; and the end point is more definite than with ordinary air. At the temperature of gas-liquid contact, less nitrogen is absorbed than in the L-D process; so, the oxygen does not have to be as pure. In addition, a part of the steam dissociates so that about 15 pct less oxygen is required than in the top blowing method.

Normally, in Europe the L-D method is used on pig irons approaching the American pig iron analysis, while the basic OV technique is used to refine pig irons with 1.5 pct to 1.8 pct phosphorus. Recently, Kosmider[1] has shown that the basic OV process can also be used on American type pig irons without the so-called after-blow.

Fig. 1 gives the operating cycle for both processes when using 45-ton converters. The L-D process uses about 25 pct scrap, while the OV process without an afterblow uses about 5 pct scrap. From the figure it can be seen that, the major factor allowing the greater production rates in the OV process is the shorter time of the blow. This is due, in the main, to the greater rate of delivery of the blast.

In order to get effective phosphorus removal, the lime:silica ratio of 3:1 should be used for both processes. According to Kosmider,[1] the OV process gives the same degree of dephosphorization as the L-D method, but this is open to question since all the burnt lime may not be in solution by the end of the blow, and in the OV process there is less scrap to dilute the phosphorus. In any event, neither process will consistently produce a steel containing less than 0.01 pct P, using a single slag, when being charged with a 0.300 pct P pig iron.

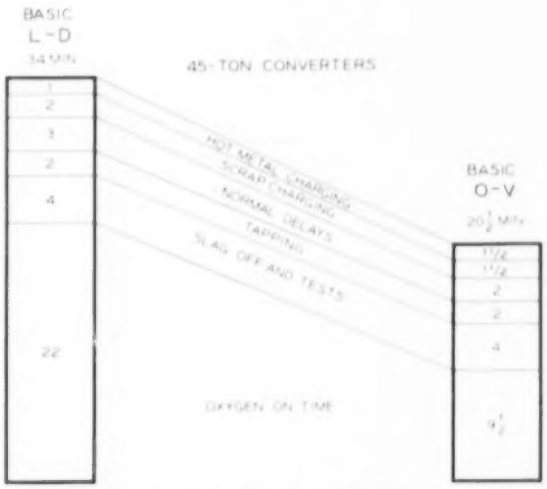


Fig. 1—Operating cycle for the L-D and OV pneumatic processes.

In both processes, the blow is continued until the flame drops. Thus, only low carbon steels are made (0.03-0.04 pct C). Some recarburization has been successfully carried out in the ladle at Dofasco, where rimmed and killed grades up to 0.2 pct C are made. In Europe recarburization to 0.6 pct C is accomplished by adding pig iron. It may be possible to meter the oxygen so that the blow can be stopped at the desired carbon level, provided phosphorus does not cause trouble. This may be easier to do in the L-D process than the OV process.

In conclusion, it can be said that plant location and local conditions will determine which of these pneumatic methods can be used to best advantage. It must be borne in mind that both of these techniques are relatively new and further research may make them even more effective to produce quality steel at a low cost.

J. E. STUKEL is with the Youngstown Sheet & Tube Co., Youngstown, Ohio.

[1] H. Kosmider, H. Neuhaus, and A. Weyer: Verblasen von Stahleisen mit sauerstoffangereichertem Wind in bodenblasenden Konverter, *Stahl und Eisen* 1954, vol. 74, p. 1473.

New Control Instruments for Bessemer Steelmaking

by P. Leroy

STEEL produced in the basic bessemer converter, or thomas converter as it is called in Europe, constitutes some 62 pct of French steel production. This is why the Institut de Recherches de la Sidérurgie française (IRSID) since its organization in 1947 has placed improvement of basic bessemer quality and conversion yield foremost in its research program. Some of the instruments developed for blowing control are now standard equipment in steel plants; others are still in the development stage; and all may also be used with acid converters.

For 70 years the blower had only two instruments at his disposal: a manometer and a chronometer. The manometer showed him the wind pressure, and the chronometer indicated the blowing time. Other than these, the blower could rely only on such empirical signs as flame appearance, slopping at the converter nose, slag appearance on converter tilting, effervescing level of the sample, appearance of the test-bar fracture, and the occurrence of ladle-skulls. While it was never contemplated doing without these empirical signs, it was desirable to put at the steelman's disposal a number of data that might be used either by the blower for controlling the operation or by the engineer for research purposes. To show the importance of such controls a steel plant producing 600,000 short tons per year will be considered.

1st Example: Minimizing Slopping

Assuming that through blowing control it is possible to gain 12 lb of metal per ton of steel by slopping reduction, the saving on a yearly basis would be 3600 short tons. This gain of 12 lb per ton is conservative, since even greater savings have been achieved in several French steel plants.[1, 2] Basic research on slopping has been carried out by means of an entirely new type flowmeter, called the *volume-debitgraphe*.[3]

If air consumption per ton of iron is too high, excess air is heated uselessly to a temperature averaging 1300°C on its way through the metal bath. This heat taken from the metal could be used to melt additional scrap. A reduction in air consumption also makes it possible to effect economies in the blowing machine operation, as well as shortening the blowing time. Part of the remedy is to increase the iron charge, but the volume-debitgraphe can also be useful in eliminating excess air consumption.

2nd Example: Thermal Control

Assuming that the end temperature averages 30°F higher than the minimum temperature necessary to prevent the formation of ladle skulls, this extra heat would have melted 25 lb of additional scrap per ton, or 7500 short tons annually. This could be done without a single additional ton of iron from the blast furnaces.

A number of advantages resulting from a good temperature adjustment should be taken into account; these include:

a) The iron lost to the slag is reduced when the temperature is low. A difference of 30°F results in a variation of about 1 pct in the iron content of thomas slag or 5 lb per ton, which makes 1500 tons annually or about a day's production.

b) When excessive temperatures are avoided, the consumption of deoxidizing ferromanganese is lower. A difference of 30°F on rimming steel results in a variation of about ½ lb per ton in the consumption of 75 pct Fe-Mn.

c) Producing low phosphorus steel is easier in the case of melts conducted at an intermediate or low temperature.

d) Steel with a low nitrogen content is obtained when the whole thermal cycle of the metal during the blow is itself lower.[4]

For thermal control of the converter some steel plants use the immersion pyrometer, which gives an accurate measure of temperature after the converter has been tilted. Unfortunately, it is then too late to correct the heat. Moreover, the final temperature is not sufficient to give any indication of the thermal evolution during the blow.

These considerations have led IRSID to conceive and develop recording pyrometers which draw a temperature curve for the blow. Two kinds of instruments have been constructed, although so far they exist only as prototypes. One is a *two-color pyrometer*[5] aimed at the metal bath through one of the tuyeres in the converter bottom. The other is a *flame pyrometer*[6] aimed at the converter flame near the nose and recording, not the brightness temperature of the flame, but its true temperature, its emission factor having been taken into account. Such instruments should make it possible to correct the thermal evolution of the charge before the end of the blow.

The Volume-Debitgraphe

This instrument is a special type of flowmeter used for recording and measuring two basic data: first the air-flow automatically expressed in Normal Temperature and Pressure, and second the air-volume blown since the beginning of the operation, which is, rather than time, the true variable characterizing the evolution of the refining.

The measurement of air-flow is effected by a transmitting linear flowmeter, connected with an orifice meter located in the wind pipe. This flowmeter is equipped with an automatic pressure compensating device which is calibrated once and for all

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to the mean temperature of the wind.

The paper strip of the receiving apparatus records the flow-curve. It is driven by an integrating device whose speed is proportional to the instantaneous wind flow. As a result, the unrolled paper length at any time is proportional to the quantity of wind blown since the beginning of the operation. A digit counter, controlled by the strip pay-off system, gives directly the total air volume forced through the converter since the beginning of the blow.

This equipment is complemented with a pressure recorder. The simultaneous interpretation of the flow and pressure curves indicates the permeability variation, or the variation in the resistance of the bath to the wind flow.

Another type of volume-debitgraphe has been developed for the use of oxygen enriched air or oxygen plus steam. In this case the true variable is the total quantity of oxygen introduced into the bath since the beginning of the blow. The volume debitgraphe may then be used as a device for proportional control.

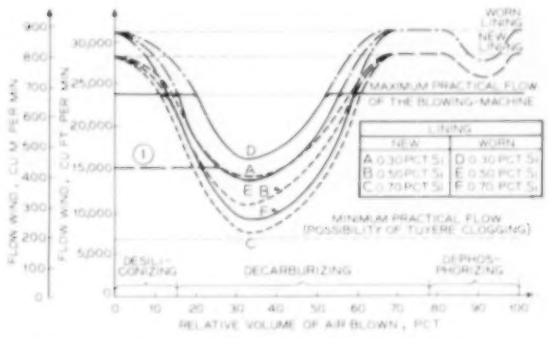

Fig. 1—Air flow curves for iron, 0.3 to 0.7 pct Si, in basic converters with new and worn linings.

In conjunction with the thomas converter, slopping was an important problem during the first half of the decarburizing period. The volume-debitgraphe made it possible to carry through an investigation[5] of the factors affecting slopping. The main conclusions were the following:

a) Slopping decreases or disappears when the static depth of the bath is reduced. Generally, the inside diameter of the new lining should be large enough for the static depth of the bath to be not more than 2-ft, but in French converters, the static depth was usually between 2-ft, 4-in. and 3-ft.

b) Slopping during the first half of the decarburizing period seems due to a swelling of the charge caused by emulsifying a silicated primary slag with a high foaming power in the metal. It is very gradually neutralized by the lime.

c) Under some conditions the tuyeres get partially clogged leading to a decrease in permeability. Blowing tests, carried out with a constant air blow, with volume-debitgraphe recording of the corresponding wind pressure, have established that during the first half of the decarburizing period, a pressure increase of about 3 to 4 psi is required to keep the air flow at a constant value. This is probably due to the tuyeres being partly clogged by the silicated primary slag, whose viscosity is high at that time. During the second half of the decarburization (never before) an actual permeability anomaly may occur, causing a heavy pressure increase which may be as high as 14 psi. This corresponds to the formation of a stopper of frozen metal on the nose of a certain number of tuyeres, and this stopper only melts during the dephosphorization. This anomaly may lead to a prolongation of the blowing time amounting to 2 or 3 min.

Such are the results afforded by the volume-debitgraphe as a research instrument, but it is also a control instrument that can be used on a routine basis.

For a converter of given shape and size, it is possible to work out experimentally, using the volume-debitgraphe, a pencil of air flow curves similar to those of Fig. 1. Each curve represents the air flow above which slopping may be expected for a given silicon content and degree of lining wear. The blower, knowing approximately the silicon content of the iron and the state of the lining, follows the curve for these conditions.

In practice when the silicon is somewhat on the high side, the blower generally prefers beginning at an air flow lower than the maximum limit of the blowing machine, so as to have a reserve of power to cope with a sudden blowability decrease at the beginning of the decarburization. Thus, he begins the blow at about 15,000 cu ft per min for a 20-ton converter, following curve A of Fig. 1.

So, in the daily routine work, the volume-debitgraphe makes it possible to blow each charge within the shortest time possible, avoid slopping, and thus increase the efficiency of the converting operation.

But this is not the only practical interest of the instrument. For example, this instrument makes it possible to make a limestone or ore addition at a precise moment of the blow when a definite volume of air has been blown. This is far more accurate than relying on the time factor. Additional advantages may be credited to this instrument when blowing with oxygen enriched air.

Two-Color Pyrometer

The two-color pyrometer is aimed at the metal bath through a tuyere in the converter bottom. It receives the light energies emitted in two narrow bands of medium waves and records the bath temperature, T, by the following basic formula which is based on the laws of Stefan and Wien:

$$\text{Log}\,\frac{i\lambda_1}{i\lambda_2} = A + \frac{B}{T}$$

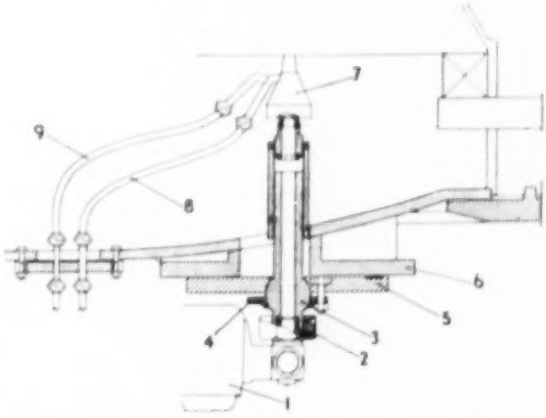

Fig. 2—Sectional view of the two-color pyrometer mounting on the converter—ref. 5.

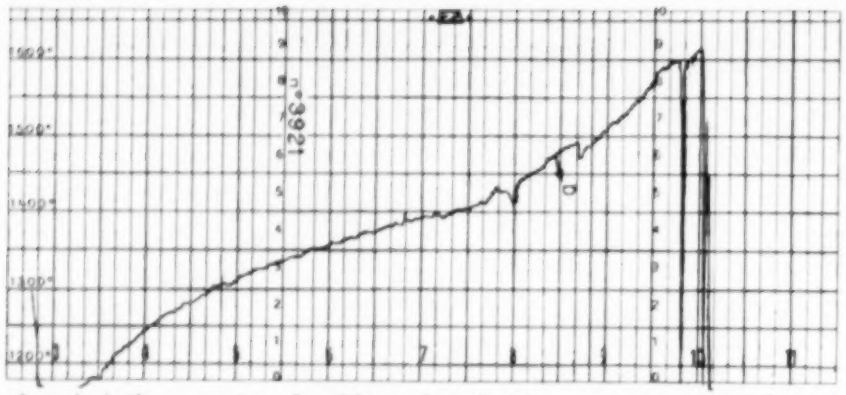

Fig. 3—Temperature curve of a thomas converter as recorded by the two-color pyrometer.

where $i\lambda_1$ is the current produced by a photoelectric cell behind a filter having a wave length of λ_1, $i\lambda_2$ is the current produced by a photoelectric cell behind a filter having a wave length of λ_2, A is a constant, B is a constant, and T is the temperature in °K.

The advantage of using the ratio of the light energies emitted on two wave lengths is that the measurement is not disturbed by factors reducing or increasing these two energies in the same ratio. Such is the case for variations of the solid aiming angle caused by wear of the converter bottom or partial clogging of the tuyere.

The instrument comprises:

1) a feeler crossing the wind-box, the mounting of which can be seen in Fig. 2; this feeler has only one active part: an electron-multiplying cell, in front of which rotates a disc bearing monochromatic filters with λ_1 and λ_2 wave lengths;

2) an electronic device which from currents $i\lambda_1$ and $i\lambda_2$ makes it possible to obtain a current, I proportional to $\text{Log} \frac{i\lambda_1}{i\lambda_2}$, hence proportional to: $A + \frac{B}{T}$;

3) a recording device, with a temperature scale;

4) an oxygen and nitrogen feed device for the aiming tuyere, whose object will be described hereafter.

The operation of this instrument in laboratory tests has never given rise to any difficulty, but in thomas steelmaking certain problems did arise. Here are two examples:

a) When ordinary air is blown in the aiming tuyere, the elongations of the recording device are higher than with tuyeres of smaller diameter, because the combustion of iron impurities at the nose of this tuyere is more rapid, thus creating a local overheating which is recorded by the instrument. To alleviate this, nitrogen has been blown into the aiming tuyere instead of air. From then on, the agreement between the final elongations of the two-color pyrometer, expressed in temperature of the calibrating black body, and the measurements effected with an immersion pyrometer, after tilting of the converter, were satisfactory, i.e. the relationship was almost linear.

b) During the blow, and especially at the end of the decarburization, it frequently happens that the aiming tuyere becomes more or less clogged with metal or slag deposits. When nitrogen is blown into the aiming tuyere, this clogging is still more frequent, but by blowing pure oxygen into the aiming tuyere it is cleared in a few seconds. It is often necessary to repeat this operation several times to ensure a thorough cleaning.

Fig. 3 shows the temperature curve of a thomas converter charge as recorded by a two-color pyrometer. The following features can be seen: a) a slight temperature decrease during the first half-minute of the blow, due to the heat absorbed by the lime and scrap; b) a heavy temperature rise up to 4 min blow, corresponding to the desiliconizing period; c) a slower temperature rise during the decarburizing period; and d) an accentuated rise during the last 3 min, corresponding to the dephosphorizing period. The small breaks on the curve correspond to partial clogging of the aiming tuyere, quickly eliminated by a short oxygen blow. It sometimes happens that these breaks are much more of a hindrance than shown in Fig. 3.

Prototypes of two-color pyrometers already have made it possible to make the following interesting observations: a) a charge with excess lime and very little scrap shows a temperature curve which is constantly higher than that of a normal charge completed at the same temperature; b) of two charges ended at the same temperature, the one with the lowest thermal cycle produces steel with the lowest nitrogen content.

The field of investigation which is opened up by this new instrument is large, and investigations are being actively continued at IRSID.[4]

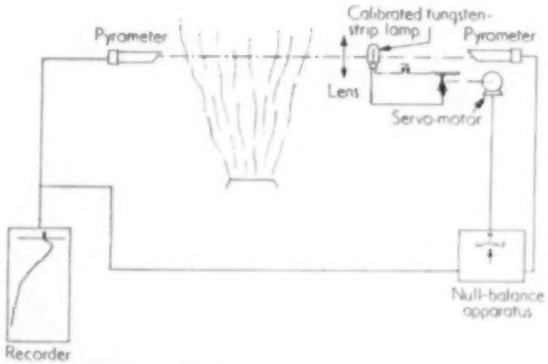

Fig. 4—Schematic diagram of a flame pyrometer installation.

Flame Pyrometer

Another technique used to gather information on the thermal behavior of the bath is by deducting it from the temperature curve of the flame. But the brightness temperature of a flame depends both on its true temperature and on its emissivity, and it is

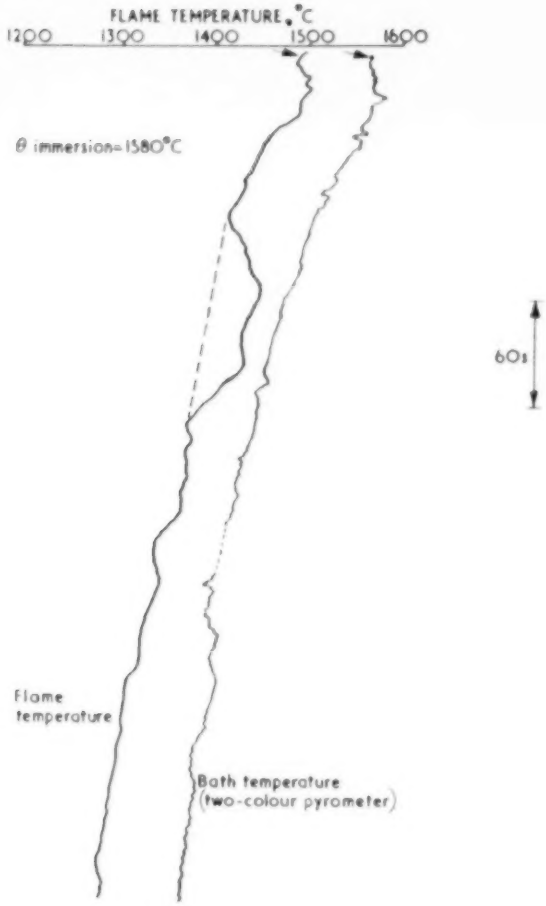

Fig. 5—Comparison of temperature curves recorded by the flame and the two-color pyrometers for the same melt.

neccessary to obtain a temperature curve which is independent of its emissivity. With this aim in view, IRSID developed an entirely new device, based on the old method of Kurlbaum, but making it automatic and turning it into a zero setting method.

A light source is located on one side of the flame (Fig. 4), and a first sighting tube equipped with a photo-cell, called a measuring pyrometer, is aimed at this source through the flame. It receives a light energy which is the sum of the energy emitted by the flame, and the energy emitted by the source and transmitted by the flame, taking into account the absorption of the flame.

A second pyrometer, called the opposition pyrometer, located behind the light source and aimed directly at it, receives the energy emitted by the source alone.

The light source is an adjustable reference lamp of the tungsten strip type. For a flame of a given temperature, there exists only one value of the light source for which the responses of the two pyrometers are identical. The theory holds that this response constitutes a measure of the true temperature of the flame.

The difficulty is to follow the variations of the flame temperature, but this has been overcome by connecting the circuits of both pyrometers in opposition on a zero setting instrument. If the flame temperature varies, the equilibrium is broken. The zero setting apparatus controls a servo-motor which, acting on the feed current of the light source, causes its brightness temperature to vary in the direction required to restore equilibrium.

The response of one of the two pyrometers is transmitted directly to a recording instrument, and after calibration, it records the curve of the true temperature of the flame.

The flame pyrometer can be used for measuring the temperature of any flame under two conditions: first, the emission factor must be greater than 0.3, which is the case for the majority of industrial flames, and second, the flame temperature must be approximately homogeneous.

Temperature measurements of the metal bath made by an immersion pyrometer at the end of the blow, show that the end temperature measured by the flame near the nose, is always lower than that of the bath by about 144°F. This discrepancy may vary slightly from plant to plant, but it remains almost constant in a given plant, thereby making it possible to forecast the final temperature of the bath.

During the decarburization, the interpretation is difficult owing to combustion of carbon monoxide at the converter nose. In order that this may not be too much of a hindrance, it is necessary that the optical axis of the pyrometer be adjusted near the converter nose.

Fig. 5 shows the bath temperature curve obtained with the two-color pyrometer and the flame temperature curve of the same melt supplied by the flame pyrometer. It is evident that the two curves are approximately parallel, except during the last two minutes of the decarburizing period when carbon monoxide is burned at the converter nose.

While the flame temperature is only an indirect means of ascertaining the bath temperature, the flame pyrometer is simple and easily installed on a converter battery.

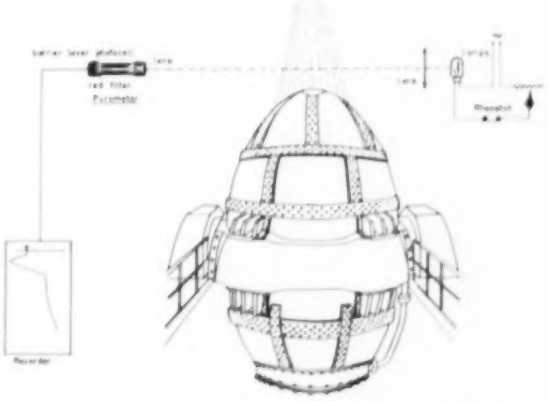

Fig. 6—Schematic diagram of an opacimeter installation.

The Opacimeter

In the case of the thomas converter, it is necessary that the end point be determined with great accuracy. If it is too early, the phosphorus content of the metal is too high, and if it is too late, the risk is an exaggerated iron loss in the slag and over-oxidation of the metal. This implies a precision in the evaluation of the end point of the blow. Up to now, the blower estimated the tilting time from the pre-

ceding melts, relying on the one hand on the time passed since the beginning of the dephosphorization, and on the other hand, and mainly, on the appearance of the flame. But this evaluation was subjective, and additional data could be supplied by the air counter of the volume-debitgraphe. But to be able to tilt the converter at the correct phosphorus level from the readings of the volume-debitgraphe, the weight of the charge must be known, and neither the iron composition nor the thermal conditions of the charge must have changed. These last two conditions are very difficult to meet in production work.

In the case of the acid bessemer converter, the end of the operation coincides with the end of the decarburizing period and is very clearly marked by a drop in the flame brightness. Thus, the blower can easily stop the blowing operation by surveying the flame. Nevertheless, about 15 years ago, H. K. Work[7] proposed and applied an interesting method to determine the end-point of the blow. This consisted of aiming a photoelectric cell at the converter flame, thereby recording a brightness temperature. By the end of the decarburizing phase, the recorded curve showed a rather steep drop, broken by a small step or kink, which could be used as an end-point signal for the acid blow.

Fig. 7—Opacity curves for hot and cold bessemer melts.

This method, applied to the basic converter, gives different results. By the end of the dephosphorizing period, the brightness of thomas converter flame, after having increased steadily from the start of this period, stabilizes at a certain value. To obtain a definite phosphorus content in the steel, it is necessary that this flat part of the curve be longer where the final temperature of the melt is higher. This close dependence upon temperature deprives the method of any accuracy.

The idea to survey the transmission rather than the emission characteristics of the flame occurred to IRSID engineers. As in the case of the acid converter, in the last moment of blowing, the flame of the thomas converter contains in suspension an ever increasing quantity of minute particles of iron oxides, usually called red fumes, which considerably alter the opacity of the flame.

Experience has shown that the opacity curve, after having gone up from the middle of the dephosphorizing period, goes through a maximum which often constitutes a good signal to stop the blow. In other cases, this point is somewhat early, and it is better to wait until the flame opacity decreases slightly and becomes stable. These two marks on the opacity curve are not too greatly affected by temperature changes. But the final shape of the curve does give qualitative information on the thermal condition of the charge. Generally, the hump of the curve is narrow and sharp for a cold charge and broad and open for a hot charge. Fig. 7 shows typical opacity curves for hot and cold melts.

To use the transmission principle, a light source, whose brightness temperature is constant and known, is placed behind the converter flame. The transmitted light is measured by means of a photoelectric cell aimed at this light source through the converter flame. The opacimeter comprises the following parts (Fig. 6): a) at the converter nose level, a light source of constant brightness, and a sighting tube equipped with a photo-cell aimed at the source through the flame, and b) a recording device whose pen is controlled by the amplified photo-cell current.

The opacimeter is now a part of the production equipment of 17 basic bessemer steel plants in Europe.

Conclusions

In the development of these instruments the purpose of IRSID was a double one:

a) To supply the steel industry with efficient research tools for fundamental study of the thomas process;

b) To provide a closer control of the blowing and thermal conditions in the daily production work in order to increase production and reduce costs.

The future will tell to what extent IRSID has succeeded.

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Herbert James French

1956 Howe Memorial Lecturer

Herbert J. French (Member 1934), vice president of the International Nickel Co. Inc., assistant vice president of the International Nickel Co. of Canada Ltd., and AIME Howe Memorial Lecturer for 1956, died in Rochester, Minn. on Aug. 17, 1955, after a long illness.

Before his death, Mr. French had laid the foundation of research on which the Howe Memorial Lecture (p. 770) was based. His associates at Inco, O. O. Miller and J. W. Sands, were able to complete the project, present the lecture, and prepare it for publication, following Mr. French's general outline.

Born in New York on May 27, 1893, he graduated from the School of Mines, Columbia University, with a degree in metallurgical engineering in 1915. Mr. French gained his early engineering experience with the American Smelting and Refining Co., serving as a chemist and assayer at the company's Murray, Utah, installations. He later returned east and became a metallurgical engineer for the General Vehicle Co., Long Island City, N. Y., a subsidiary of the General Electric Co. In 1917 Mr. French was appointed civilian inspector of materials for the U. S. Army Signal Corps, and continued this work when it was later absorbed into the Bureau of Aircraft Production. Subsequently he was appointed district inspector in Philadelphia for the Pittsburgh (Ordnance Metallurgical) office, later transferring to Pittsburgh.

After World War I Mr. French became an assistant physicist on the metallurgical staff, U. S. Bureau of Standards, Washington, D. C. During his years with the Bureau, he was successively associate physicist, metallurgist, senior metallurgist, and assistant chief, division of metallurgy.

In 1929 Mr. French joined International Nickel as a metallurgist at the company's Bayonne, N. J., research laboratory. Transferring to the development and research division, New York, in 1931, he took charge of alloy steel and iron development, becoming assistant manager of this division in 1943. Mr. French's appointment as an Inco vice president came in March 1947. Previously, he was appointed assistant vice president of the International Nickel Co. of Canada Ltd. in January 1947.

Mr. French served the War Production Board during World War II as senior technical consultant in charge of the metallurgical and specifications section of the iron and steel branch. When this section of the WPB was organized into the steel division, he was appointed chief of the metallurgical branch. From March 1944 to September 1945 Mr. French served as assistant director.

Herbert French was well known not only for his prolific contribution to the metallurgical literature, for which he received numerous awards, but also for his prolonged service to the profession through its technical societies. He was a past president of ASM, and was the Campbell Memorial Lecturer for that group in 1933. Mr. French was honored by the American Society for Steel Treating in 1931 when he was awarded the Henry Marion Howe Medal. A series of lectures he gave in 1941 before the Fourth Western Metal Congress in Los Angeles was later published in book form under the title *Alloy Constructional Steels*.

The Transactions papers appearing in the JOURNAL OF METALS *during 1956 will subsequently appear in AIME Transactions Volume* 206, *and may be permanently referenced to that volume.*

Howe Memorial Lecture—1956

Some Aspects Of Hardenable Alloy Steels

When untimely death overtook the eminent metallurgist who had been chosen to deliver this year's Howe Memorial Lecture, he was in the midst of gathering his material and developing new data in the thorough and competent manner in which he handled all such assignments. Out of regard and affection for Herbert French, and because we were his chief assistants with respect to this item of his activities, we have endeavored, to the best of our ability, to complete Mr. French's discourse along the lines which we believe he intended. We are sure that, had he been spared, you would be presented with a much more profound and better integrated discussion, but under the circumstances we beg your indulgence for any failure to meet the standards of excellence which always characterized Herbert James French's metallurgical writings and lectures.

We are presenting Mr. French's discourse as we have envisioned it.—*Oscar O. Miller and John W. Sands.*

by Herbert J. French

Prepared by Oscar O. Miller and John W. Sands

IT was my good fortune to have known Henry Marion Howe when I was a student at the School of Mines, Columbia University, some 20-odd years after he had gathered the material for his monumental work on the *Metallurgy of Steel*, published in 1888.[1] His life span, unfortunately, did not extend to the period of most rapid growth of alloy steels, but he had envisioned their future importance very early in our century, as illustrated by this passage from the second edition of his book *Iron, Steel and Other Alloys*, published in 1906:[2] "Alloy steels," said Howe, "have come into extensive use for important special purposes, and a very great increase of their use is to be expected."

And how right he was! In the year 1906 alloy steel ingot production in the United States is estimated to have been not in excess of 100,000 tons. In one of the World War II years more than 13 *million* tons were produced, and during one month of that year production actually reached an annual rate of over 15 million tons which is two thirds of the entire steel output of the year 1906 in which Howe made this forecast.

The commercial history of constructional alloy steels may be considered to encompass somewhat less than a century. Of course, the groundwork had been laid much earlier by pioneers from Faraday to

H. J. FRENCH, Member AIME, deceased, was Vice President, International Nickel Co. Inc., New York.

After the death of Mr. French in August 1955, two of his associates in the International Nickel Co., O. O. MILLER, Member AIME, Head, Steel Section, Research Laboratory, Bayonne, N. J., and J. W. SANDS, Member AIME, Development and Research Div., New York, prepared the lecture from his data.

TP 4265C. Manuscript, Apr. 11, 1956. New York Meeting, February 1956.

Mushet, whose illuminating investigations had pointed the way, but it was not until Julius Baur established a plant in Brooklyn for the manufacture of chromium steels in 1869 that commercial production worthy of the name began.[3] Progress commercially, however, was slow until the successful exploitation of nickel steels in 1885 by Marbeau in France. The unusual properties of these steels inspired the famous Riley discussion of their characteristics before the British Iron and Steel Institute in 1889.[4] The first major effect of this paper was an immediate investigation by the United States Navy of nickel steel armor plate made by the Schneider Works in Creusot, France. The results of this careful testing program almost overnight, made all unalloyed armor plate obsolete for the navies of the world. This was one of the most abrupt changes of pattern in the history of steel applications. The reasons are quite apparent from a contemporary illustration, Fig. 1, of the results obtained at Annapolis in 1890. These tests were made at short range with 8-in. armor-piercing projectiles. The 3½ pct Ni alloyed plate, in the center, did not crack at any point. In fact two of the five projectiles even failed to penetrate completely. Obviously the same cannot be said of the normal carbon steel plate on the left or of the patented *compound* plate on the right. The latter is believed to have been a composite of a high carbon steel face plate combined with a soft steel backing plate.

For nearly two decades thereafter, during which a transition from military to industrial applications was proceeding, nickel, sometimes coupled with chromium, dominated as the alloying element in alloy steels.

In retrospect, the commercial approach to alloy steels in the early years of our century seems naive, but in another 50 years steel metallurgists may look back on the practices of 1955 with a similar smug

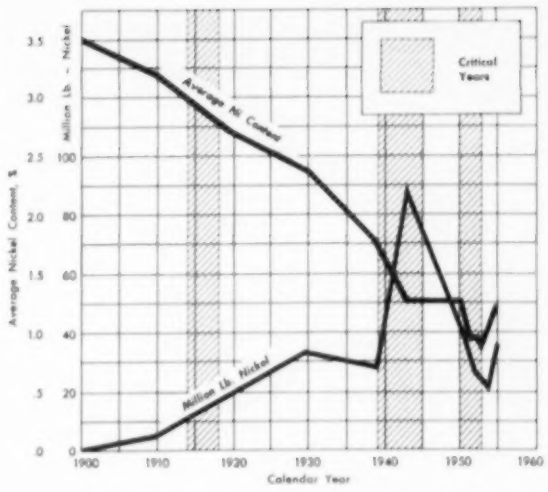


Fig. 2—Estimated nickel in shipped weight and average nickel content of nickel-containing engineering alloy steels.

attitude. Nevertheless, it is revealing, in the light of our present knowledge, that Elwood Haynes, an automotive pioneer writing in 1906, would boast that in 1899 a car built by Haynes and Apperson successfully made a trip from Kokomo, Ind., to New York City, a distance of about 1000 miles, without *serious* breakage of any kind.[5] The axle was made of alloy steel and, according to Haynes, was the first such steel to be used in an automobile. He further stated that this steel was used in automotive axles for five years without a single case of breakage. The steel was not only free from *crystallization* (how my old friend H. W. Gillett would have cringed at that

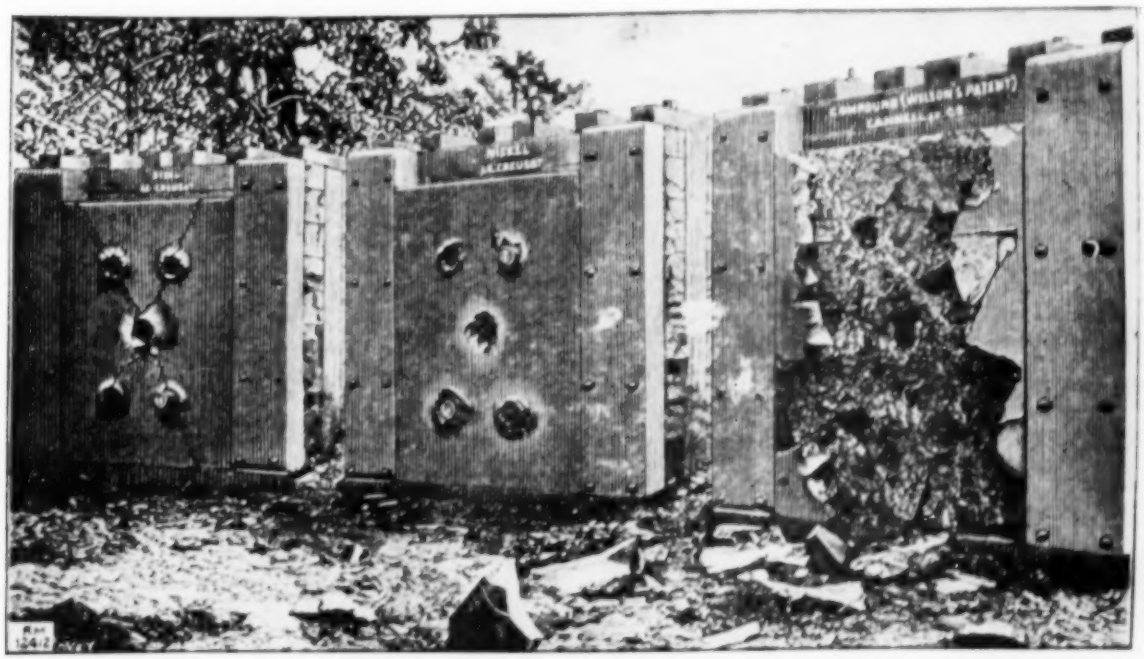


Fig. 1—Ballistic tests by U. S. Navy on armor plate of carbon (left), nickel (center), and unalloyed *compound* (right) steels at Annapolis in 1890 (after contemporary woodcut). The tests were made at short range with 8-in. armor-piercing projectiles.

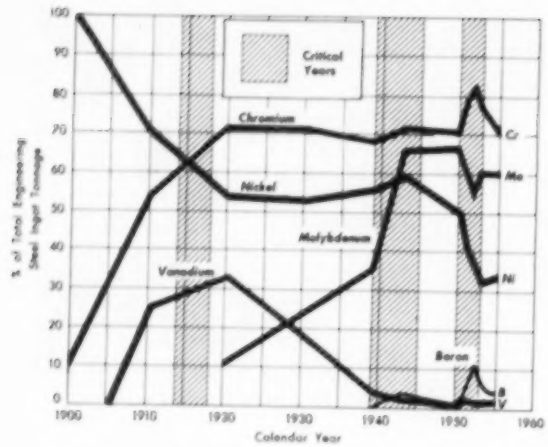


Fig. 3—Estimated percentage of engineering steel grade mix containing indicated element (after Mitchell to 1952).

statement!) but possessed the amazing tensile strength of over 100,000 psi!

The earliest steels were generally heavily overalloyed as a matter of insurance. They could be subjected to the crudest of heat treatments or otherwise abused and still deliver superior properties. Unnecessary overalloying, however, could not be tolerated for long, on an economic basis if for no other reason. As technological advances were made in steelmaking (especially with respect to grain size control, largely accomplished by deoxidation with silicon plus aluminum), heat treating, inspection, and engineering design, it was found that the leaner and less expensive steels could be satisfactorily employed in a majority of applications. The most sudden and sharpest shifts in this direction quite naturally occurred during emergency periods when government enforced conservation measures precipitated alterations which would have evolved much more slowly, if at all, under normal circumstances.

It is fortunate indeed that this retrenchment took place. If, for example, the pattern of 1900 had still

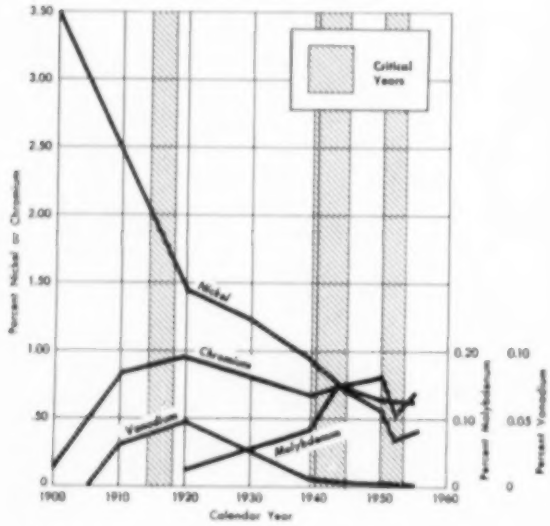


Fig. 4—Average percentage of content of indicated element in the total engineering steel production.

prevailed in 1943, the amount of nickel required for United States production of low alloy steels alone would have totaled some 400 million lb, or considerably more than the world production at that time, Fig. 2. This chart shows the rapidly rising total consumption to 1943 in the face of sharply decreasing percent content. Even with the nickel-containing steels reduced from 100 to 56 pct of the total low alloy steels produced and their average nickel content from 3.50 to 1.25 pct, it is estimated that approximately 84 million lb of nickel were incorporated in low alloy steels shipped from the mills in 1943.

Figs. 3, 4, and 5 are designed to provide a somewhat panoramic view of the kaleidoscopic variations which have occurred in the engineering alloy steel picture since the start of our century. They are based largely upon the informed estimates so ably presented by John Mitchell in the October issues of *Metal Progress* in 1950[6] and 1952,[7] which are supplemented in these charts by information issued by the AISI. The term *engineering alloy steels* in the charts refers to low alloy constructional steels mainly identifiable by AISI and SAE classification numbers. It does *not* include stainless steels, electrical silicon sheet steels, tool steels, or proprietary high strength low alloy structural steels.

Fig. 3 indicates the variation over the years 1900 to 1955 in the percentage of these steels containing each of the four major alloying elements: nickel, chromium, molybdenum, and vanadium. In 1900 virtually all the steels contained nickel, with 10 pct of them also carrying chromium. The latter steels were preponderantly of the Krupp composition, containing about 4¼ pct Ni and 1½ pct Cr, developed for ordnance applications by the Krupp works at Essen, Germany. The Krupp composition, incidentally, has proved of such durability that it, together with variations such as the AISI-SAE 3300 and 9300 steels, is still in considerable demand, particularly in the carburizing grades for the most severe applications.

In 1905 vanadium-containing steels, sparked by the Ford Motor Co., entered the picture, and for some 15 years grew steadily more popular. They reached their peak in 1920, when they accounted for one third of the total. Their decline began with the introduction of molybdenum steels, the use of which grew rapidly. Thus between 1920 and 1950 the predominant feature was the rise of the molybdenum steels and the parallel decline of the vanadium steels, the nickel and chromium-containing share varying much less.

The sharp increase in the molybdenum line in the World War II period was due to effective government conservation measures. Molybdenum was introduced into many steels to replace part of the nickel or chromium, forming the *triple alloy* Ni-Cr-Mo National Emergency compositions.

During the Korean period, on the other hand, it was necessary, again under government control, to retrench in both nickel and molybdenum. The major load was thus shifted to the more available chromium, sometimes bolstered by addition of boron to increase hardenability.

With the removal of controls in late 1953, a tendency can be noted to revert to the pre-emergency pattern, a perfectly natural reaction.

Considerable time has been devoted to Fig. 3 because of its basic nature. However, it can convey a misleading impression unless one clearly recognizes

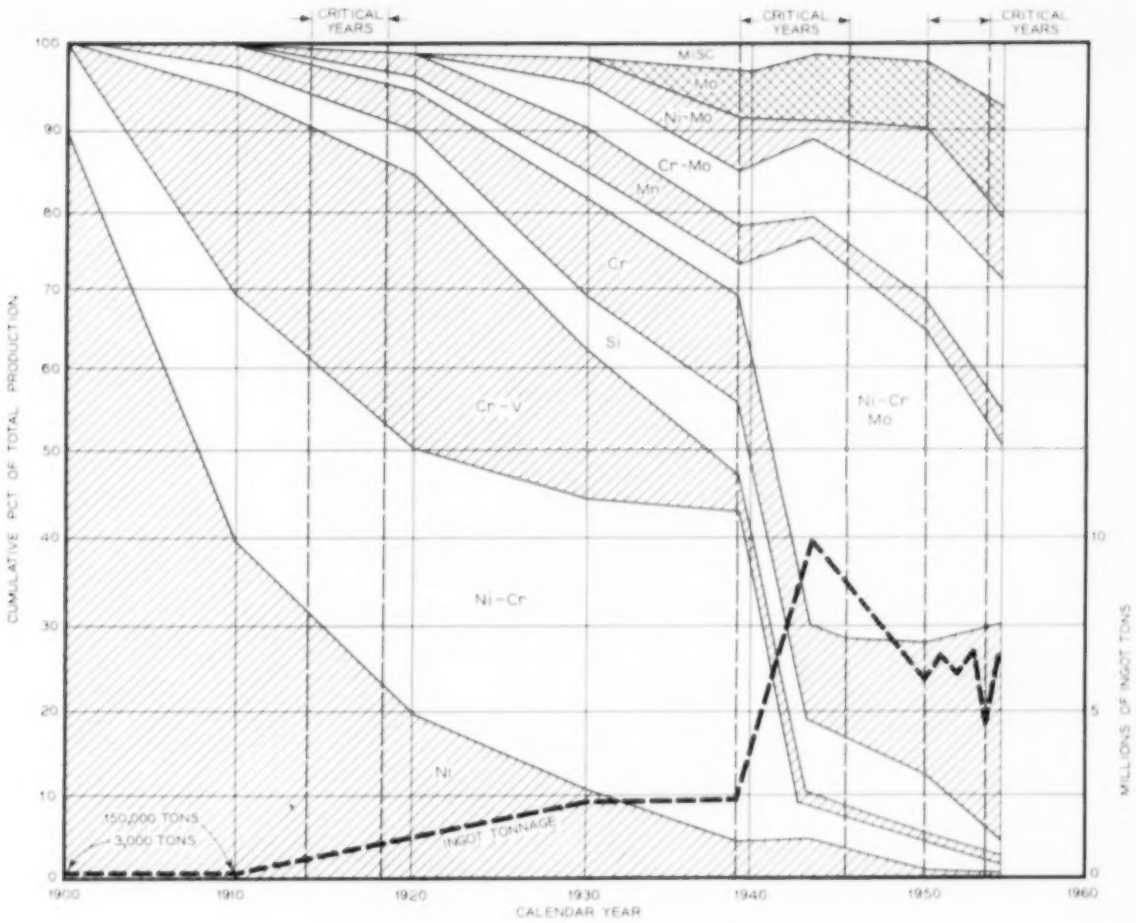


Fig. 5—Estimated grade mix of total SAE-AISI ingot production (after Mitchell to 1950).

that the chart gives no indication whatever of any variations in the average percentage of a given element employed in the share which contains it. Thus, while the chromium and nickel curves change little between 1920 and 1950, the relationship between these elements and molybdenum and vanadium is influenced by the fact that the average nickel and chromium contents of the steels containing them were continuously decreasing, while the corresponding molybdenum and vanadium contents remained nearly constant.

The share of production containing the element and the percentage of the element employed therein average out for comparison purposes if the mean content of the individual element in the *total* production, as distinguished from the fraction containing the element, is plotted, as has been done in Fig. 4. Expanded ordinate scales for molybdenum and vanadium, as indicated by the right hand scales on the chart, are necessary for clarity because these elements, when used, are employed in smaller percentages than are chromium and nickel. Expanded scales are used for molybdenum and vanadium: five to one for molybdenum and ten to one for vanadium.

The development of the National Emergency steels in World War II was expedited greatly by the rapid method of hardenability measurement developed by Jominy and Boegehold[9] and the data of Janitzky and Baeyertz[9] and Patton,[10] which tend to show that room temperature tensile, and to some extent room temperature notch-impact, properties of all tempered martensites are essentially equivalent. Limitations are discussed further along in the paper. By combining these two developments, both of which are discussed in greater detail later, a simple approach to maximum conservation of alloying elements in time of heavy consumption was at hand. The procedure comprised adding the alloys, mainly

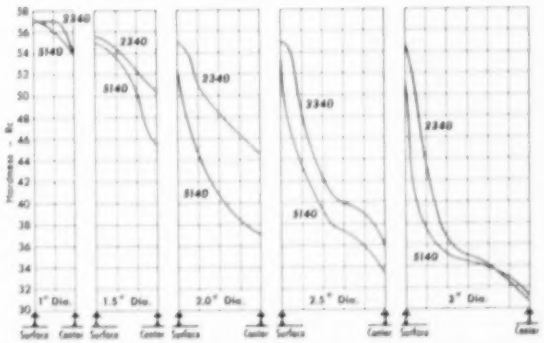


Fig. 6—Hardness distribution curves for quenched rounds of 2340 and 5140 steels.

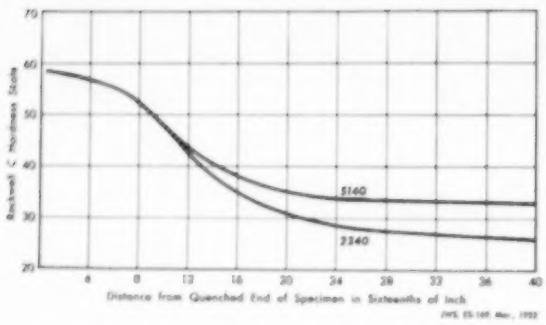


Fig. 7—Jominy end-quench tests on 2340 and 5140 steels.

nickel, chromium, and molybdenum, judiciously proportioned to secure the hardenability required for the application in view. Thus the desired objective was at least approximately attained with the least expenditure of strategic alloys together with an equitable distribution of the alloy load in accordance with the available supplies of the three metals.

The effect of the enforced use of the steels so quickly devised according to these precepts upon the grade mix of engineering alloy steels was dramatic, as Fig. 5 clearly shows. Up to 1939 the nickel, Ni-Cr, and Cr-V steels were still accounting for about 50 pct of production. Within four short years 80 pct of this group had been supplanted by the leanly alloyed steels of the Ni-Cr-Mo *triple alloy* type which, as the chart shows, was previously the smallest class of all. This shift corresponded with, and largely made possible, the indicated better than fourfold production increase.

It cannot be denied that the concept of the equivalence of all steels of the same apparent hardenability with respect to certain mechanical properties greatly helped us to bridge the World War II and Korean emergencies. However, the fact that the enforced conservation measures caused so many pleas for special dispensations to be allowed to continue with standard grades was strong evidence that the substitute materials, although they could be made to perform adequately if fabricated and conditioned with great care, were lacking in certain intangibles. This circumstance tends to cast doubt upon the validity of the hypothesis that the properties of tempered martensites are independent of chemical composition.

In point of fact large differences exist between tempered martensites of equal hardness and hardenability. These differences are not indicated by simple room temperature tensile tests. No simple testing method for evaluating the basic characteristics which lead to widely varying performance has yet been devised. Nevertheless, experience frequently shows certain steels to perform satisfactorily while others of ostensibly the same hardness and tensile properties will fail miserably in the same service.

Standard Types of Alloy Steels under Discussion

The procedure followed, in general, is to use the type number to indicate the chemical composition of each steel. The system is that employed by the SAE and the AISI. The use of four numbers is common practice. The first two indicate the alloy content and the last two show the carbon content (actually 100 times the percentage of carbon). To indicate an alloy type, without regard to carbon content, the last two numbers are replaced with zeros. The following are the standard alloy types used herein:

AISI-SAE Steel Type	Approximate Alloy Content, Pct
1300	1.8 Mn
2300	3.5 Ni
4100	1 Cr, 0.2 Mo
4300	1.8 Ni, 0.8 Cr, 0.25 Mo
4600	1.8 Ni, 0.25 Mo
5100	1 Cr
8600	0.6 Ni, 0.5 Cr, 0.2 Mo
Modified 4300	1.6 Si, 1.8 Ni, 0.8 Cr, 0.3 Mo, 0.1 V

Hardenability and Its Measurement

At the outset of this section it is necessary to define *hardness* and *hardenability* because an appreciation of both is essential to understanding the heat treatment of steels. *Hardness* is the intensity of hardening and is expressed numerically on one of a number of empirical scales, such as Rockwell, Brinell, or Vickers. *Hardenability* may be defined as the tendency of steel to transform (when cooled from the austenitic condition) to martensite essentially free from ferrite or ferrite-carbide aggregates which are decomposition products of lower hardness. Thus the manner or rates of austenite transformation determine the hardenability of a steel, whereas the intensity of the hardening is represented by the magnitude of the hardness achieved.

Our knowledge of the relationship between mass and cooling rate in the hardening of steel was developed to our present concepts of hardenability and physics of quenching by the basic work of Portevin,[11] French, [12, 13] Scott,[14] and Grossman, Asimow, and Urban.[15] To this list may be added Grossmann's later work[16] on calculation of hardenability from chemical composition. A fundamental understanding of the hardening of steel and origin of ferrite-carbide aggregates was provided by the studies on isothermal transformation of austenite by Davenport and Bain[17] and Bain.[18, 19] A little later, the fundamentals of the transformation of austenite to martensite were reported by Greninger and Troiano.[20] Hundreds of investigations have sprung from the groundwork laid by these studies, but a recounting of them is beyond the scope of the present discussion.

The most direct and precise measure of hardenability is critical cooling rate, a concept which goes back almost 40 years to the work of Portevin.[11] Work on quenching and critical cooling rates by French and associates[12, 13, 21–24] at the National Bureau of Standards nearly 30 years ago indicated that, although hardness of quenched steel is maximum at or

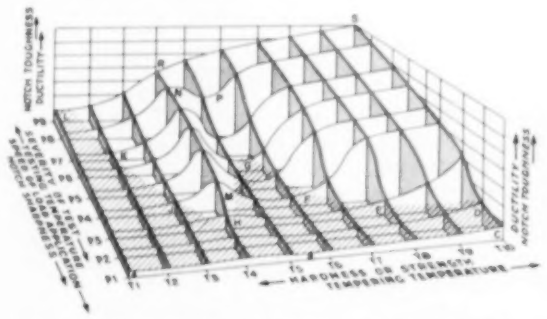


Fig. 8—Relationship between hardness or strength, severity of test, and ductility in quenched and tempered hardenable steels.

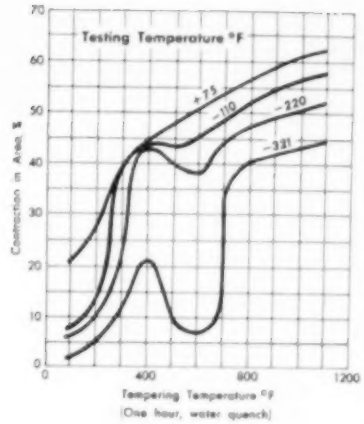


Fig. 9—Effect of tempering temperature on low temperature tensile ductility of 1340 steel quenched to martensite (after Ripling). Figures shown on curves are testing temperatures in °F.

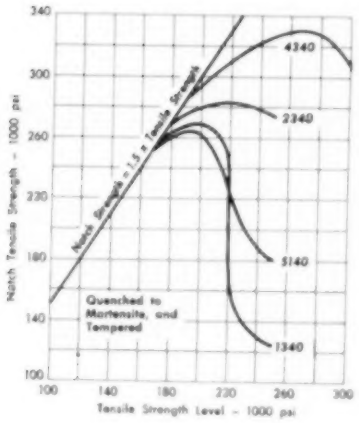


Fig. 10—Notch strength of four 0.40 pct C steels.

above the critical rate, it is not appreciably less after cooling at somewhat slower rates. Thus it was shown long ago that high hardness alone is not a sufficient criterion of full hardening and that one should also examine the microstructure. In recent years numerous more convenient methods for the study of hardenability have all but replaced the direct determination of critical cooling rates. Although these short cuts have provided much useful information, too frequently they have not included an appraisal based on the amount of martensite present. Consequently, it has been very encouraging to see a curve of percent martensite on each end-quench hardenability curve in a recent publication.[25]

Hardenability can be completely and satisfactorily indicated by a method, such as that used by Bain,[26, 27] comprising a series of curves showing distribution of hardness across a radius or diameter of a series of round bars quenched in any specific manner. Such data can be correlated closely with commercial quenching of steel. Hardness vs depth curves from surface to center for a series of rounds ranging in size from 1 to 3 in. in diam are shown in Fig. 6, which indicates that this particular 3.5 pct Ni 2340 steel possesses substantially greater hardenability than the 1 pct Cr 5140 steel. For example, at ¼ in. below the surface of the 2-in. rounds, the 2340 steel hardened to Rc 52, whereas the 5140 steel hardened only to Rc 45; furthermore, perhaps the persistence of a substantial hardness difference virtually to the surface may be of greater significance. This difference is not shown by the end-quench hardenability data in Fig. 7; in fact, the slight variation of the two curves, if significant at all, actually favors the 5140 steel. These and similar observations show that the end-quench hardenability test[7] is not always capable of indicating significant differences in hardenability, such as are shown by hardness gradient over the cross section of quenched parts. Troiano and Klingler[27] have shown that such differences, although not detected by the end-quench test, may reflect substantial variations in microstructure, mechanical properties, and eventual performance. Thus it appears that the limitations of the end-quench test must be appreciated along with its well known advantages, which include convenience, speed, and suitability for the study of carburized cases.

A martensitic structure on quenching is related to the critical cooling rate and is the goal inherent in the concept of hardenability. Quenched steels described as *martensitic* nearly always retain some austenite if cooled at, or faster than, the critical cooling rate. If cooling is slower than the critical rate, the steels are said to be *slack quenched* and contain one or more of the following constituents: ferrite, pearlite, bainite, and, unless the cooling rate is very slow, an appreciable quantity of austenite. Attention will first be centered on the properties of structures entirely martensitic prior to tempering and then on the effect of slack quenching. Finally, the effect of retained austenite, a subject of great interest to the author for many years,[28] will be considered.

Dissimilarity in Mechanical Properties of Tempered Martensites

One aspect of research on steel has been the development of the philosophy in America that hardenability is the dominant factor and that the mechanical properties of all tempered martensites of the same hardness and carbon content are alike, irrespective of the percentage of other alloy elements. This philosophy has resulted from a too broad interpretation of the work of Janitzky and Baeyertz[2] and Patton.[29] Their work comprises a significant advance, as has been indicated, in understanding the factors involved in obtaining desired room temperature tensile properties, so widely used in engineering. The limitations, listed by Patton, are 1) carbon range limited to range of 0.30 and 0.50 pct, 2) room

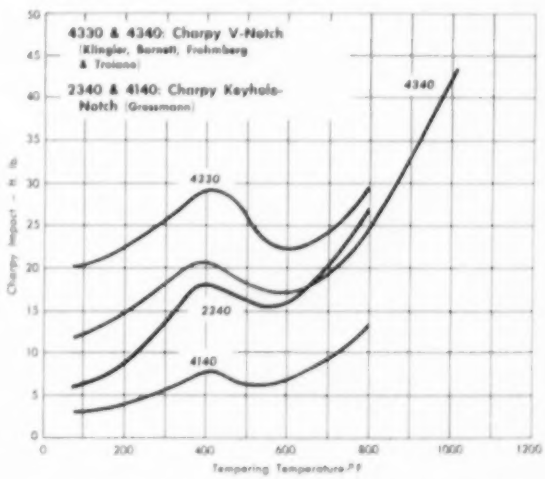


Fig. 11—Effect of tempering temperature on notch toughness at 75°F of four alloy steels quenched to martensite.

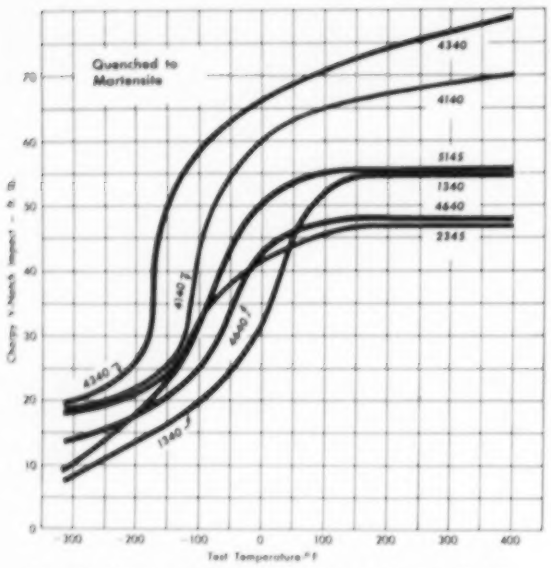


Fig. 12—Notch toughness of six alloy steels quenched to martensite and tempered to Rc 33 through 35. The 5145 curve terminates at the left directly above the 1340 curve.

temperature ductility and impact within a tensile-strength range of 110,000 to 200,000 psi only, and 3) the steel must be quenched completely to martensite. Today we are interested in strength levels above 200,000 psi, where Patton's data are quite scattered, and work in the last decade indicates that any similarity in the mechanical properties of tempered martensites of different chemical composition depends on the method of evaluation, in other words, the type of test. Consequently, it seems timely to review this entire philosophy.

Unfortunately, room temperature tensile and impact tests, restricted to a maximum strength level of 200,000 psi, represent only a small portion of the possible conditions, shown in Fig. 8, under which steel may be used. Fig. 8 is a three-dimensional schematic diagram relating: 1) hardness or strength which is inversely related to the tempering temperature, 2) severity of test which is affected by such variables as testing temperature, speed of load application, and notch sharpness, 3) ductility as indicated by notch toughness, tensile reduction of area, notch-tensile strength, and similar criteria. Such a diagram summarizes schematically a great amount of testing experience on tempered martensites, as will be shown presently. First, however, it needs some explanation.

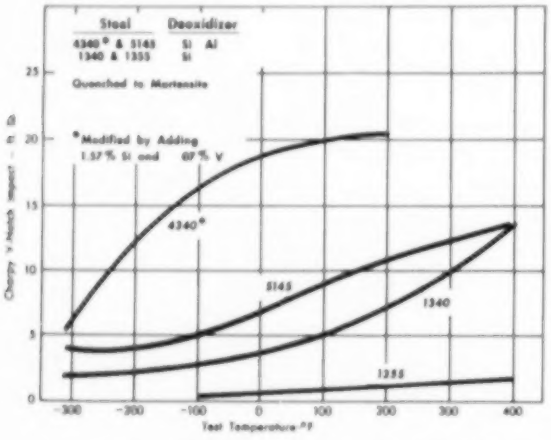


Fig. 13—Notch toughness of four steels oil quenched to martensite and tempered at 400°F.

A discussion of Fig. 8 must be prefaced by emphasizing that it is *only schematic* and that, therefore, the various dimensions are purely relative. The ductility axis is vertical; thus, the height of the roof represents ductility or notch toughness. The front axis is hardness or strength, which decreases as tempering temperature increases. The axis running front to back represents severity of test or use induced by changes in temperature, notch acuity or sharpness, and speed of loading which, in turn, determine degree of constraint and multiaxiality of loading.

Table I. Chemical Composition of Steels Investigated

AISI-SAE Steel Type*	Chemical Composition, Pct								
	C	Mn	Si	Ni	Cr	Mo	V	Al†	N
Fine Grain Type‡—Deoxidized with Silicon and Aluminum									
1340	0.43	1.79	0.24	0.11	0.07	Nil	—	0.020	0.006
2345	0.44	0.83	0.26	3.55	0.06	0.03	—	0.055	0.008
4140	0.41	0.82	0.23	—	0.95	0.16	—	0.018	0.005
4340	0.40	0.82	0.29	1.72	0.85	0.25	—	0.017	0.010
4640	0.42	0.76	0.24	1.78	0.18	0.26	—	0.032	0.010
5145	0.45	0.68	0.17	0.04	0.95	0.02	—	0.024	0.001
Modified 4340§	0.38	0.77	1.57	1.82	0.84	0.32	0.07	0.027	—
Coarse Grain Type—Deoxidized with Silicon**									
1340	0.41	2.02	0.41	0.03	0.08	Nil	—	—	—
1355	0.56	1.82	0.29	—	—	—	—	—	—
2340	0.41	0.91	0.32	3.31	0.08	0.01	—	—	—
5140	0.41	0.86	0.34	0.06	0.98	0.01	—	—	—

* Some are not in the standard list at present or are slightly outside the specified range; however, this identification is used for convenience.
† Acid soluble; that is, alumina is not included.
‡ Commercial heats made in basic open hearth or basic electric-arc furnace.
§ Modified by high silicon and molybdenum, and by 0.07 pct V.
** Commercial induction-furnace heats, except 1355, which was made in a laboratory induction furnace.

In Fig. 8 the coastal plane, *ABCDEFGHJKL*, represents minimum ductility, the brittle condition, caused by high hardness (low tempering temperature), severe constraint, or an unfavorable combination of these variables. As tempering temperature is increased from *T*1 to *T*4, going from left to right on the front axis, the ductility of the tempered martensite increases to produce the ridge *MN* on the *T*4 front-to-back rib between severity conditions *P*4 and *P*8. This ridge drops to the brittle coastal plane at *H* only under the severe conditions of test or use represented by *P*1 to *P*3. Tempering martensite in the range *T*5 to *T*6 produces the valley *PG*, which represents the so-called *500°F embrittlement*. Above *T*6 the ductility rises as tempering temperature is increased, except that significant embrittlement may develop in the vicinity of *T*8 to *T*9, representing tempering temperatures of 850° to 1100°F, if time in this region is longer than about 1 hr. For simplicity we will assume that tempering time is short enough to minimize this temper-embrittlement difficulty to an insignificant amount.

In Fig. 8 room temperature tensile tests, such as those of Patton,[10] occupy a small region in the vicinity of *RS*, at the right rear; consequently, one would expect fairly high, uniform ductility in his results because conditions are mild. At the same time it is obvious that *RS* represents only a small portion of conditions under which steel may be tested or used.

Table II. Heat Treatment of Steels for Study of Effect of Chemical Composition If Full or Slack Quenched Prior To Tempering to Rc 32 to 35

AISI-SAE Steel Type*	Austenitizing† Temperature, °F	Austenitizing† Grain Size, ASTM	Quenched to Martensite Quench Medium	Quenched to Martensite Tempering‡ Temperature, °F	Quenched to Martensite Hardness, Rc	Slack Quenched to Rc 40 Tempering‡ Temperature, °F	Slack Quenched to Rc 40 Hardness, Rc
1340	1525	8	Water	950	35	725	33
2345	1500	8	Oil	950	35	775	35
4140	1550	9	Oil	1000	35	800	35
4340	1550	8	Oil	1200	33	1000	34
4640	1550	7 to 8	Oil	1175	35	925	32
5145	1575	8	Water	950	35	800	35

* These steels are the fine grain type, see Table I.
† At temperature for 1 hr.
‡ Water quenched after a 1 hr temper.

As conditions of test or use become more severe, for example by lowering the temperature, the ductility of steel decreases most markedly in the region of *500°F embrittlement*, corresponding to the valley *PG* in Fig. 8. The work of Ripling[29] on unnotched specimens of 1340 steel slowly loaded in the relatively mild tensile test illustrates this change in ductility, as shown in Fig. 9. The curve for a test temperature of 75°F shows no deterioration in reduction of area if tempered in the range 500° to 700°F, whereas the curves for −110°, −220°, and −321°F, representing successively more severe conditions, show successively more evidence of *500°F embrittlement* as testing temperature is lowered.

The use of low test temperatures is not the only way to increase the severity of the tensile test. If room temperature tensile tests are made on notched specimens, the constraint imposed by the notch may become great enough not only to detect various types of embrittlement but also to detect significant differences between tempered martensites at high strength levels (above 200,000 psi). Such differences are not detected by tests of unnotched tensile specimens at room temperature.

Sachs and associates,[30, 31] who developed the notch-tensile test, have shown that the notch-tensile strength increases one and a half times as fast as the tensile strength, as indicated by the diagonal straight line in Fig. 10, until a limiting value, characteristic of the type of steel being tested, is reached. Above this value the notch strength begins to lag. Sachs has shown that above the breakaway point notch strength is controlled by the notch ductility, as indicated by reduction of area at the root of the notch. Conversely, therefore, the notch strength in this region is a measure of the notch ductility. Thus the present data indicate that at high strengths notch ductility is least for 1340 and increases progressively for the 5140, 2340, and 4340 steels.[32] This illustrates that, as already mentioned, the room temperature notch-tensile test is capable of distinguishing between alloy steels of different chemical composition.

Notch-impact tests, such as Charpy or Izod tests, are inherently more severe than tensile tests of unnotched specimens. It is not surprising, therefore, to find that Charpy notch-impact tests at room temperature differentiate between steels of different chemistry. This is shown in Fig. 11 by data from two sources,[33, 34] one being Grossmann's Howe Lecture in 1945. These curves show the ridge corresponding to the 400°F temper and the *500°F embrittlement* valley. Thus they fit well into the general scheme of things in the schematic diagram, Fig. 8.

Notch-impact data at a series of test temperatures comprise a particularly good way to illustrate the notch toughness of different steels. A large amount of testing experience indicates that a significant criterion of notch toughness is the test temperature at which the energy absorbed reaches some relatively low value in the range of 10 to 20 ft-lb,[35] the same energy level preferably being chosen for comparing the same group of steels. The data in Fig. 12 show that sizeable differences in notch toughness of tempered martensites do exist between steels with different chemical compositions. The steels are the fine grain type and are the first six listed in Table I.

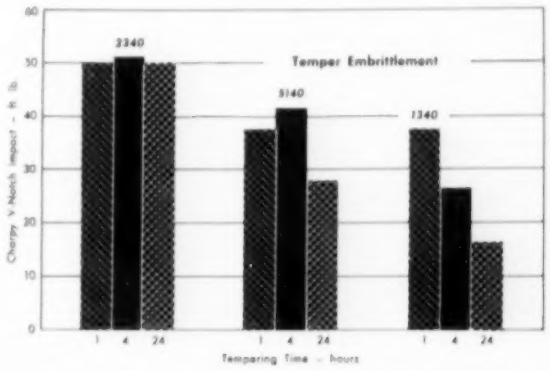


Fig. 14—Notch toughness at room temperature of 2340, 5140, and 1340 steels water quenched and tempered at 1000°F, showing development of temper embrittlement.

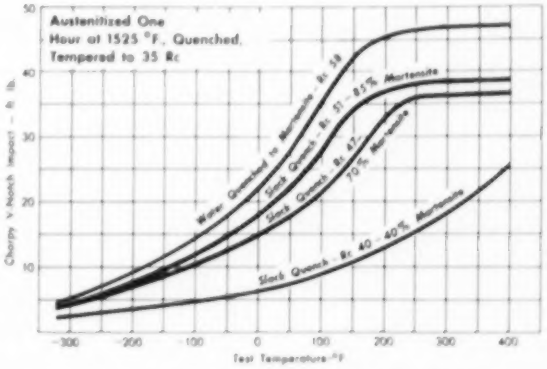

Austenitized One Hour at 1525 °F, Quenched, Tempered to 35 Rc
Water Quenched to Martensite – Rc 38
Slack Quench – Rc 37 – 85% Martensite
Slack Quench – Rc 37 – 70% Martensite
Slack Quench – Rc 40 – 40% Martensite
Charpy V Notch Impact – ft. lb.
Test Temperature °F

Fig. 15—Effect of slack quenching on notch toughness of 1340 steel.

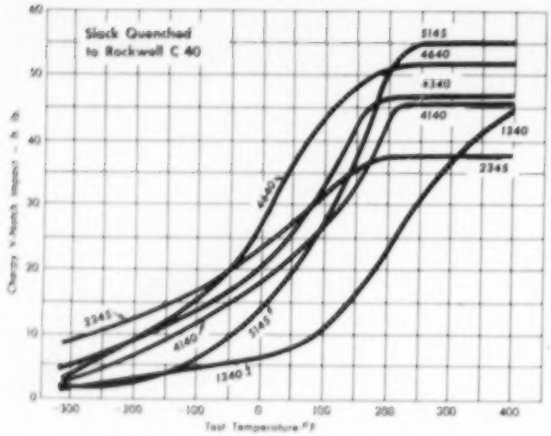


Fig. 16—Notch toughness of six alloy steels slack quenched to Rc 40 and tempered to Rc 32 through 35. The 4340 curve terminates immediately below the 2345 curve.

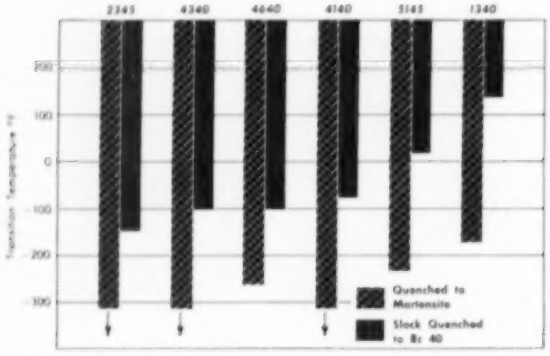


Fig. 17—Charpy V-notch-impact transition temperature (15 ft-lb) of six steels full or slack quenched prior to tempering to Rc 32 through 35.

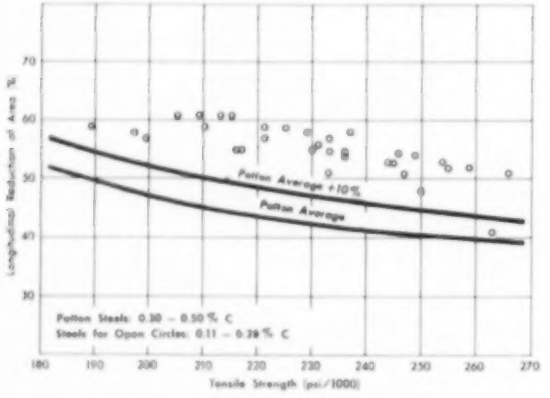

Patton Average +10%
Patton Average
Patton Steels: 0.30 – 0.50 % C
Steels for Open Circles: 0.11 – 0.28 % C
Longitudinal Reduction of Area %
Tensile Strength (psi/1000)

Fig. 18—Influence of carbon content on reduction of area (after Busby, Paxton, and Hawkes).

Details of their heat treatment, comprising quenching to martensite before tempering to Rc 33 through 35, are given in Table II.

The trends in Fig. 12 may be summarized by noting that 1) 4345 is best and 1340 is worst, 2) 2345, 4140, 4640, and 5145 are intermediate, and 3) at the lowest test temperatures 5145 definitely joins 1340 in poor behavior. The carbon range of the group is narrow: 0.40 to 0.45 pct. Almost identical data on a different set of fine grain commercial steels of the same six AISI-SAE types were obtained by Baeyertz, Craig, and Sheehan,[86] the only significant difference in the results being that the 4140 did not make as good a showing as it does in Fig. 12.

Sizeable as the variations are in Fig. 12, they do not approach the tremendous differences which can develop, as shown in Fig. 13 by four martensites which were tempered at 400°F and differ in transition temperature, using 10 to 15 ft-lb as the criterion, by almost 600°F. The 4340, modified as indicated, has a transition temperature of about −200°F as compared to about +400°F for the 5145 and the 1340. The difference in the deoxidation practice between the 4340 and the 1340 partially accounts for the wide variation between them. The silicon deoxidized 1355 steel, which is higher in carbon than the others, remained brittle when tested at 600°F and only reached 10 ft-lb on testing at 800°F. Thus, the 10 ft-lb transition temperatures of the modified 4340 and the 1355 differ by 1000°F. However, the potential difference is probably even greater, because the 1355 steel received the additional toughening treatment of an 800°F temper during testing. This experiment was, as you may suspect, designed deliberately to emphasize the wide spread of the possible differences which similarly tempered martensites may exhibit. The chemical composition and heat treatment of the steels in Fig. 13 are given in Tables I and III, respectively.

Table III. Heat Treatment of Steels for Study of Effect of Chemical Composition if Quenched to Martensite Prior to Tempering at 400°F

AISI-SAE Steel Type*	Austenitizing† Temperature, °F	Austenitizing† Grain Size, ASTM	Quench Medium	Tempering‡ Temperature, °F	Tempered Hardness, Rc
Modified 4340	1650	4 to 7	Oil§	400	54.5
5145	1575	6 to 8	Oil§	400	55.5
1340	1675	5 to 6	Oil	400	52
1355	1675	5 to 6	Oil	400	51

* Modified 4340 and 5145 are fine grain type; 1340 and 1355 are coarse grain type. See Table I.
† At temperature for 1 hr.
‡ Water quenched after a 1 hr temper.
§ Cooled also to −320°F in liquid nitrogen within about 10 min after oil quenching.

When steels are tempered in, or slowly cooled through, the temperature range 850° to 1100°F, many are susceptible to a *disease* known as temper embrittlement.[87, 88] The notch-impact test provides a convenient method of evaluating this susceptibility, as shown in Fig. 14 for the 2340, 5140, and 1340 steels austenitized, water quenched to martensite, tempered at 1000°F for 1, 4, or 24 hr, water quenched, and tested at room temperature. These steels were made and deoxidized similarly with silicon alone, see Table I, yet they differ significantly in susceptibility to temper embrittlement: the 2340 showing none; the 5140, some; and the 1340, most. These trends are in general agreement with the data of Taber, Thornlin, and Wallace.[89]

The data in Fig. 14, backed by extensive notch-impact tests representing many tempering and testing temperatures, should not be interpreted to mean that temper embrittlement cannot be developed in 2340 steel. On the other hand these data and other

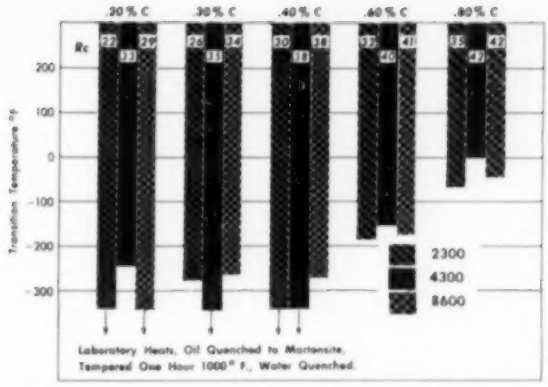


Fig. 19—Effect of carbon content on Charpy V-notch impact transition temperature, based on 12 ft lb (after Baeyertz, Craig, and Sheehan).

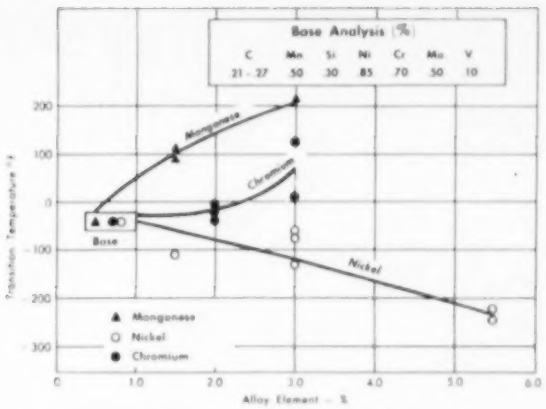


Fig. 20—Effect of three alloy elements on Charpy V-notch transition temperature taken at 50 pct of maximum energy (data from Busby, Paxton, and Hawkes).

testing experience do show conclusively that the rate of development of, or severity of, temper embrittlement and *500°F embrittlement* increases in the order 2340, 5140, 1340. This again demonstrates that all tempered martensites are not alike. It is also interesting to note that the order for these three steels is the same as shown by the notch-tensile and notch-toughness data in Figs. 10 and 12, respectively.

Dissimilarity in Mechanical Properties if Slack Quenched and Tempered

Thus far attention has been centered entirely on steels quenched to martensite (plus some retained austenite) before tempering. In commercial quenching this is the exception rather than the rule, as shown by studies in England and America. A study of American practice shows that less than 20 pct of representative machine parts[6] are quenched essentially completely to martensite before tempering. The remainder are slack quenched to a microstructure comprising martensite plus ferrite and/or ferrite-carbide aggregates formed at relatively high temperatures. As the martensite is diluted with these high temperature products, the as-quenched hardness drops as shown in the following tabulation which, although the values listed are for 1340 steel, is typical of the general trend in carbon and alloy steels:

Hardness, Rc	Martensite, Approximate Pct	High Temperature Products, Approximate Pct	Type of Quench
58	100	0	Full
51	85	15	Slack
47	70	30	Slack
40	40	60	Slack

Thus the drop in hardness indicates the relative amount of high temperature transformation products. The transition temperature, based on the frequently accepted criterion of 15 ft-lb, is raised 50°, 100°, or 350°F above that of full martensite by slack quenching to Rc 51, 47, or 40, respectively, and tempering to a constant hardness of Rc 35, Fig. 15. This is the coarse grain type of 1340 steel, Table I, and its heat treatment for study of slack quenching is shown in detail in Table IV.

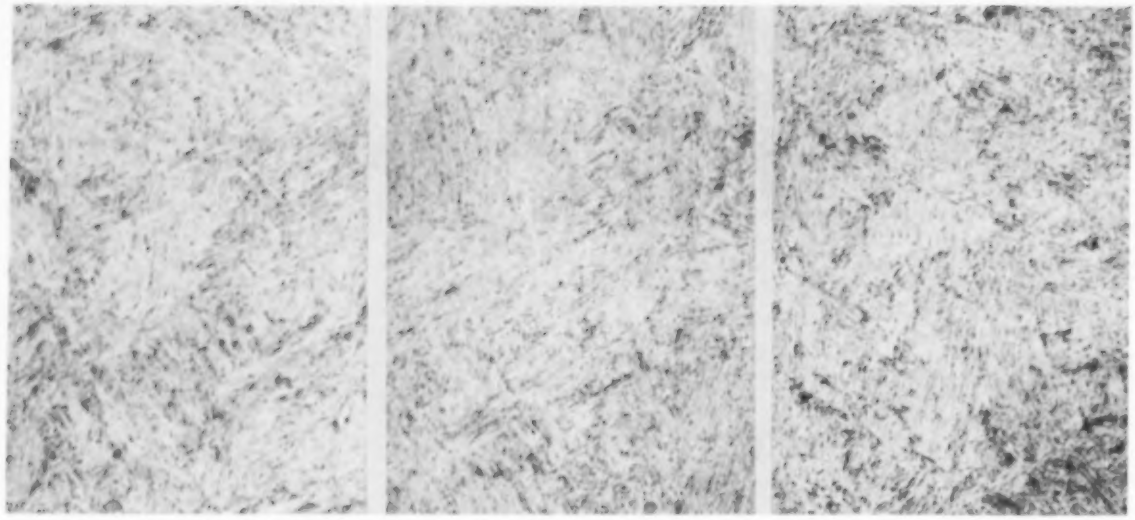
Inasmuch as slack quenches are common in industry, it is desirable to examine a number of alloy steels to determine if chemical composition affects notch toughness or ductility in this heat treated condition. This has been done for the first six steels in Table I, which shows that all are the fine grain type. They were slack quenched to Rc 40 and subsequently tempered to a Rc range of 32 through 35. Details on heat treating are given in Table II. The results in Fig. 16 show that the temperature at which the steels reach the 10 to 20 ft-lb range differs by more than 200°F. Certainly all are not alike, even though the curves for some cross one another.

Comparison of the curves in Fig. 16 with those for the fully quenched and tempered condition, Fig. 12, shows that slack quenching has emphasized the difference between the steels, thus suggesting that the effect of chemical composition is greater in the case of slack quenching. This is better illustrated in Fig. 17, in which the steels are arranged, from left to right, in the order of decreasing notch toughness for the slack-quenched condition, using the criterion of transition temperature based on 15 ft-lb. The difference between the two bars for each steel is a measure of the rise in transition temperature caused by slack quenching. This marked rise in transition temperature, produced by slack quenching, is emphasized in the following table, which provides a more quantitative aspect and also shows the variations between steels of different types:

AISI Type	Transition Temperature, °F, Based on 15 Ft-Lb: Slack Quenched to Rc 40	Quenched to Martensite	Increase Caused by Slack Quenching, °F
2345	−150	Less than −320	More than 170
4340	−100	Less than −320	More than 220
4640	−100	−260	160
4140	−70	Less than −320	More than 250
5145	10	−228	238
1340	135	−175	310

In summary we may say that the steels differ in transition temperature by 285°F as slack quenched prior to tempering and by more than 145°F if quenched to martensite before tempering. This degree of slack quenching has raised the transition temperature on the average by more than 200°F. These numbers, although interesting, are in themselves of less significance than the fact that their relative magnitudes are indicative of the general or relative performance to be expected under adverse conditions of use.

The value of data on transition temperatures of fully quenched and tempered or slack quenched and



a—2.5 pct austenite (54.5 Rc) Oil quenched and cooled to —320°F.

b—5 pct austenite (53.5 Rc) Quench arrested at 390°F for 25 min.

c—10 pct austenite (52 Rc) Quench arrested at 440°F for 1 hr.

Fig. 21—Light micrographs show modified 4340 steel austenitized at 1650°F, quenched as indicated, and tempered at 400°F. Specimens were etched with super picral-nital. X1000. Area reduced approximately 15 pct for reproduction.

tempered steels is diminished considerably by the almost complete lack of statistical data in this field. For example, we do not know the amount of variability to expect in transition temperature between heats made by the same steelmaking practice or by different steelmaking practices in the same or different mills. If we had such statistical information we could evaluate the significance of these data in terms of the degree of certainty of the various trends. As things are now, however, we must be content with the general trends observed and the inferences made therefrom.

Table IV. Heat Treatment of 1340 Steel to Show Effect of Degree of Slack Quenching

Cooling from 1525°F Austenitize*	Tempering Temperature, °F†	Tempered Hardness, Rc
Water Quench to Rc 58, Martensite	1000	34
Slack Quench to Rc 51	900	35
Slack Quench to Rc 47	850	35
Slack Quench to Rc 40	725	35

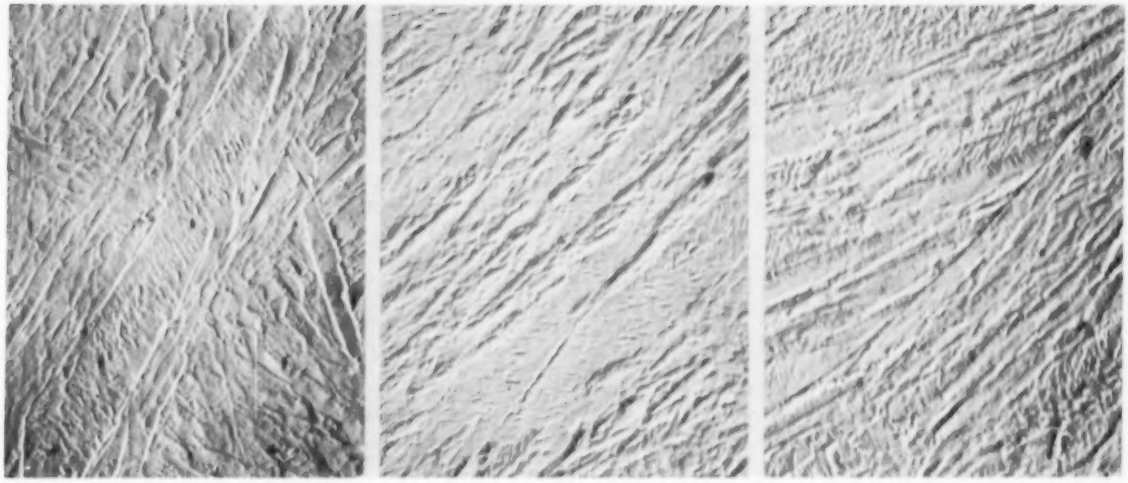
* Austenite grain size after 1 hr at 1525°F is 7 to 8 (ASTM scale) in this coarse grain type of 1340 steel.
† Specimens were tempered for 1 hr and water quenched.

Effect of Alloy Elements on Ductility and Notch Toughness

It has been known for a long time that, in general, an increase in the carbon content of steel for any given hardness and type of microstructure is often accompanied by a decrease in ductility.* The recent work of Hawkes[41] illustrates the effect of carbon on the reduction of area of fully hardened and tempered steels at a tensile strength of 150,000 psi. More recently Busby, Paxton, and Hawkes[42] showed that, for the same strength level, the reduction of area is higher for steels in the 0.11 to 0.28 pct C range than in the 0.30 to 0.50 pct C range studied by Patton,[10] as shown by Fig. 18. The effect of carbon on notch-impact transition temperature of three types of alloy steel (all oil quenched to martensite, tempered at 1000°F, and water quenched) is indicated in Fig. 19, which was prepared from selected data from the work of Baeyertz, Craig, and Sheehan.[38, 43] Fig. 19 shows that as carbon is decreased from 0.80 to 0.40 pct for the 2300, 4300, and 8600 steels, there is a decided lowering of transition temperature. No significant decrease in transition temperature occurs in reducing the carbon content progressively from 0.40 to 0.30 to 0.20 pct; in fact, there is a slight indication of an increase in transition temperature. This is surprising because a decrease in transition temperature (increased ductility) was expected. About all we can say is that if there is a decrease in transition temperature in going from 0.40 to 0.20 pct C, these data do not suffice to show it. Furthermore, the few scattered published data fail to support a decrease in transition temperature in going below 0.40 pct C. Further work is needed in this area.

Quantitative data on the effect of other alloy elements in the quenched-tempered condition are very scarce, but an analysis of the data of Busby, Paxton, and Hawkes[42] shows the effects of increasing manganese, nickel, and chromium on transition temperature in the base composition indicated in Fig. 20. The 16 fine grained steels used for Fig. 20 were austenitized at 1600°F, quenched to martensite, and tempered for 24 hr at 212°F to a hardness range of Rc 49 through 54. The curves in Fig. 20 indicate that transition temperature is increased greatly by manganese, increased a little by chromium, and decreased greatly by nickel. Alone these data would be of insufficient weight to be convincing, but they confirm the trends presented above. Data are also available on silicon which, if about 1.5 pct is added, lowers transition temperature on tempering in the vicinity of 500° to 600°F by raising the temperature of 500°F embrittlement, as shown by the work of Allten and Payson[44] and Shih, Averbach, and Cohen.[45] The beneficial effect of silicon is limited to this tempering range.

* Probably this is not always true except for short tempering times because of temper embrittling effects in the vicinity of 850° to 1100°F.



a—2.5 pct austenite (54.5 Rc)
Oil quenched and cooled to —320°F.

b—5 pct austenite (53.5 Rc)
Quench arrested at 390°F for 25 min.

c—10 pct austenite (52 Rc)
Quench arrested at 440°F for 1 hr.

Fig. 22—Electron micrographs show modified 4340 steel austenitized at 1650°F, quenched as indicated, and tempered at 400°F. Specimens were etched with super picral. Negative parlodin replica was shadowed with germanium at 30° from the normal to plane of replica. X10,000. Area reduced approximately 35 pct for reproduction.

A point of considerable interest is that manganese lowers transition temperature very significantly in low carbon normalized steels, as indicated by several technical articles and work to be published shortly by two of the author's associates. Unfortunately this reversal of the effect of manganese is just as much a mystery as the unexpected behavior of carbon at low levels.

The mechanism by which the alloy elements effect changes in ductility and notch toughness is unknown except that silicon retards tempering by retarding the formation of platelet cementite, which is associated with 500°F embrittlement.[39, 40] This knowledge about the effect of silicon and the fact that notch toughness is affected greatly by microstructure suggest that eventually we may find that the other elements exert their influence through microstructural changes not yet detected. Such studies on tempered martensite are needed. The improvement in notch ductility, usually accorded to nickel, may be associated with microstructural changes during tempering. On the other hand, it may be associated with changes in the properties of the ferrite matrix, such as development of a subgrain structure possibly associated with dislocations, which appear to be intimately related to metal's flow and fracture.

Effect of Retained Austenite

A subject which has been controversial for many years is the effect of retained austenite on the mechanical properties and service life of steel. French has discussed its beneficial effects in relation to fatigue life[38] and room temperature notch toughness.[41] Cohen and co-workers reported that the most striking effect of retained austenite is a decrease in yield strength and elastic limit,[42] and demonstrated that, as might be expected, it is strain sensitive and may undergo transformation during mechanical testing.[43] The latter observation may be associated with its tendency to add to fatigue life which is enhanced, within limits, by an increase in hardness, such as would result on transformation of the retained austenite to martensite.

More work is needed to bridge the gap between the effects of retained austenite as indicated by laboratory tests and its effect on service life of machine parts. For many years some metallurgists have suggested that it may be highly beneficial in heavy duty applications, such as carburized gears for trucks, yet others claim that it is detrimental even in ordinary applications. Work is now in progress to relate the amount of retained austenite to the life of carburized steel gears.[44]

No data have appeared on the effect of retained austenite on transition temperature. Therefore, it was decided to do a little exploratory work. For this purpose a steel is needed that can be heat treated to a martensitic matrix in which the amount of retained austenite can be varied widely and in which a Charpy V-notch-impact of 15 ft-lb, or more, develops on tempering at 400°F. This temperature is near the maximum allowable to avoid significant transformation of austenite. Such steels are scarce; however, the modified 4340 steel containing 1.6 pct Si and 0.07 pct V, Table I, meets these requirements reasonably well.

Three levels of austenite, 2.5, 5, and 10 pct as revealed by X-rays, can be retained in an essentially tempered-martensite matrix of this steel by employing the heat treatments shown in Fig. 21. The term *essentially tempered martensite* is used advisedly, because the two quenching arrests, necessary to stabilize more austenite than present in the directly quenched specimen, may contribute to bainite formation. This is indicated by the isothermal transformation diagram, which, incidentally, is almost identical for this modified 4340 steel[45] and regular 4340 steel.[46] The specimens were etched in an unsuccessful attempt to reveal the expected bainite, rather than retained austenite which requires a different etching procedure. Thus the three micrographs, all at a magnification of X1000, in Fig. 21 are practically identical. Electron micrographs at X10,000, Fig. 22, also show no discernible difference among the three specimens. These observations are

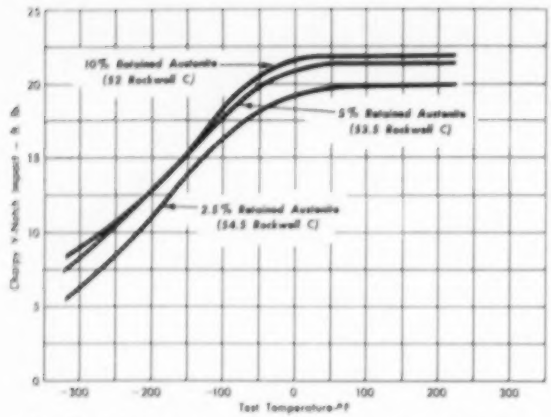


Fig. 23—Influence of retained austenite on notch toughness of modified 4340 steel tempered at 400°F.

in agreement with considerable metallurgical experience, and with recently published electron microscopic work,[77] in which there was no significant difference in microstructure between tempered martensite and tempered low temperature bainite.

It seems reasonable to assume from the foregoing discussion that the only significant difference in microstructure, produced by the heat treatments indicated in Figs. 21 and 22, may be the 2.5, 5, and 10 pct retained austenite. In Fig. 23 the Charpy impact curves for these three levels of retained austenite, over the usual testing temperature range, do not indicate any major effect of retained austenite. Yet it should be mentioned that the differences which do exist indicate that the retained austenite, within limits, may improve low temperature notch toughness. Further work is needed in this field to provide convincing data.

Summary

As predicted by Howe in 1906, alloy steels have enjoyed a large and continuous growth. This growth has been accompanied by lower and lower percentages in the steels of the two initial alloying elements, nickel and chromium, as improvements in steelmaking, heat treatment, and design of machine parts were made and as other elements, such as vanadium, molybdenum, and boron, were to be useful alloy elements in hardenable steels. Artificial alloy shortages, induced by abnormal production requirements during national emergencies, have accelerated changes in alloy steel compositions.

Chemical composition significantly affects the ductility and notch toughness of tempered martensites, as demonstrated by supporting data. This is in disagreement with a growing philosophy in America that all tempered martensites are alike and that, therefore, hardenability is the only significant factor in steel selection. The effect of chemical composition is even more pronounced if steels are slack quenched, as is the rule rather than the exception in commercial practice, to give a mixture of martensite and ferrite plus ferrite-carbide aggregate prior to tempering.

The data which have been presented herein suggest that the mechanical properties of the triple alloy Ni-Cr-Mo steels are, in general, superior to those of the double or single alloy steels. This is a happy circumstance because, as is well known, the triple alloy steels comprise the most efficient use of the elements for imparting hardenability. The amount of these elements in scrap continues to increase, conservation therefore is greatly aided by concentrating on the triple alloy grades with or without vanadium and boron.

Acknowledgments

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Mechanism of Electrical Conduction in Molten Cu S-Cu Cl and Mattes

The specific conductance and its temperature dependence were measured over the entire composition range of the molten Cu_2S-CuCl system. At a typical temperature of 1200°C, 10 mol pct of the ionically conducting CuCl reduced the specific conductance from about 77 ohm^{-1}cm^{-1} for pure Cu_2S to about 32 ohm^{-1}cm^{-1}, and 50 mol pct CuCl reduced the conductance to that for pure CuCl—about 5 ohm^{-1}cm^{-1}. The nature of electrical conduction in molten Cu_2S, FeS, CuCl, and mixtures was studied by measuring the current efficiency of electrolysis at about 1100°C. The Cu_2S, FeS, and mattes were found to conduct exclusively by electrons, but addition of 15 wt pct CuS to Cu_2S produces a small amount of electrolysis. Addition of CuCl to Cu_2S suppresses electronic conduction, and ionic conduction reaches almost 100 pct at a CuCl concentration of about 50 mol pct. These facts are interpreted in terms of electron energy level diagrams by analogy to the situation in solids.

by Ling Yang, G. M. Pound, and G. Derge

RESULTS of electrical conductivity studies on molten Cu-FeS mattes as a function of composition and temperature have been reported.[1] The specific conductances ranged from about 100 ohm^{-1} cm^{-1} for pure Cu_2S to 1500 ohm^{-1} cm^{-1} for pure FeS. This is in sharp contrast with the low specific conductance of molten ionic salts for which the transfer of electricity is by migration of ions in the field. In general, these ionically conducting molten salts, such as NaCl, KCl, CuCl, etc., have a specific conductance of the order of magnitude of 5 ohm^{-1} cm^{-1}. It was concluded on the basis of this evidence that molten FeS and Cu_2S exhibit electronic conduction. Pure molten FeS has a small negative temperature coefficient of specific conductance, resembling metallic conduction, while pure molten Cu_2S has a small positive temperature coefficient, resembling semiconduction. The molten Cu_2S-FeS mattes follow a roughly additive rule of mixtures, both with respect to specific conductance and temperature coefficient. Savelsberg[2] has studied the electrolysis of molten Cu_2S and Cu_2S + FeS. He concluded that while molten Cu_2S is an electronic conductor, there is some ionic conduction in molten Cu_2S + FeS, owing to the formation of the molecular compound $2Cu_2S \cdot FeS$ and its dissociation into Cu^+ and FeS_2^{-} ions. The present work does not verify his results.

Chipman, Inouye, and Tomlinson[3] have studied the specific conductance of molten FeO and report a high specific conductance, about 200 ohm^{-1} cm^{-1}, of the same order of magnitude as that found for molten mattes, and a positive temperature coefficient. They interpret these results in terms of *p*-type semiconduction in the ionic liquid by analogy to the situation in solid FeO.[4] Simnad and Derge[5] detected appreciable ionization in molten FeO by means of electrolytic cell efficiency measurements.

In order to verify the conclusion that electrical conduction in molten Cu_2S and mattes is electronic, and to gain further insight into the structure of molten sulfides, the following investigations were carried out in the present work:

1) The specific conductance, σ, of the molten system Cu_2S-CuCl was measured as a function of temperature over the entire composition range. As discussed later, molten CuCl is an ionic substance. It was thought that if molten Cu_2S were simply ionic in nature, addition of small amounts of CuCl might not have a catastrophic effect in lowering the high conductance of the Cu_2S. On the other hand, if much electronic conduction occurs, addition of the ionic CuCl should have a large effect in destroying the electronic conduction.

2) The electrolytic cell efficiency of the following molten systems was measured at about 1100°C in specially designed cells: Cu_2S; Cu_2S + FeS, 50:50 by wt; FeS; Cu_2S + CuS, 15 wt pct; Cu_2S + CuCl, 5.9 to 46.4 mol pct; and CuCl. This gives a direct measure of the fraction of current carried by ions in these melts. Further, the cell efficiency, extrapolated to zero ionic current, is given by

$$\text{cell efficiency} = \sigma_{ionic} / (\sigma_{ionic} + \sigma_{electronic}). \quad [1]$$

σ_{ionic} for molten Cu_2S would be expected to be no greater than that for molten CuCl, whose σ_{ionic} is about 5 ohm^{-1} cm^{-1}, as will be seen in the following. $\sigma_{electronic}$ for molten Cu_2S is of the order of 100 ohm^{-1} cm^{-1}.[1] Thus, a large increase in cell efficiency from 0 to values of 10 to 100 pct upon addition of CuCl to Cu_2S would indicate destruction of the electronic conductance.

Conductance Measurements

Experimental Procedure—The apparatus and experimental method were the same as those described in detail in connection with the study of electrical conduction in molten Cu_2S-FeS mattes.[1] A four terminal conductivity cell and an ac poten-

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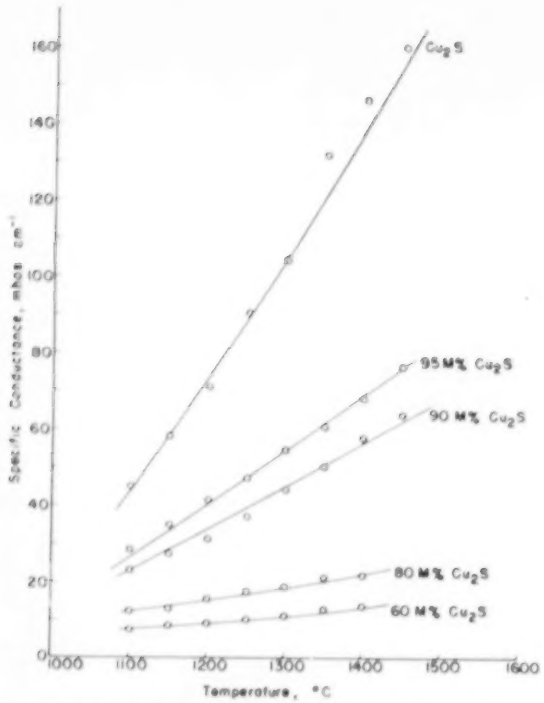

Fig. 1—Graph plots specific conductance of melts of Cu_2S with CuCl.

tiometer circuit were used to measure specific conductance. The tubes of the cell were of silica. Spectrographic graphite rods served as electrodes. The molten Cu_2S-CuCl was contained in a dense Alundum crucible. The melt was held at temperature in an induction heated tube furnace with graphite heater under a helium atmosphere. Temperature was measured with a calibrated Pt—Pt-Rh thermocouple.

The Cu_2S-CuCl specimens were prepared from the cp grade compounds by prefusing in a graphite crucible under a helium atmosphere.† After the conductance measurements, the specimens were analyzed for copper and sulfur by methods described in a previous publication.[1] The specimens were analyzed for chlorine by an evolution method. The powdered specimen is treated with dilute nitric acid in a closed system equipped with a reflux condenser and a collecting flask containing $AgNO_3$ solution to collect the HCl gas evolved. The AgCl precipitate is filtered, dried, and weighed. The contents of the specimen flask are also filtered, and this filtrate is treated with $AgNO_3$ to recover any dissolved chloride. As previously discussed, a small amount of desulfurization occurs in the course of the experiment, and some of the volatile CuCl is lost. However, the analyses show that the nominal compositions indicated in Figs. 1 and 2 are correct to within 5 pct. Inasmuch as the analyses for sulfur are subject to some uncertainty as previously considered,[1‡] it is deemed sufficient for the present purposes of the conductance work to give only the nominal compositions.

† The phase diagram for the Cu_2S-CuCl system is thought to be a simple eutectic.[6]

‡ The analyses for copper and iron are considered to be fairly precise. These analyses are the important ones in the electrolysis work.

Conductance Results—The assembled specific conductance data for molten Cu_2S-CuCl systems are given in Fig. 1. It is seen that the ionically conducting CuCl has a great effect in reducing the specific conductance of molten Cu_2S. This effect is better demonstrated in the plot in Fig. 2, where specific conductance is plotted vs mol pct Cu_2S at a typical temperature of 1200°C. It is seen that small additions of CuCl greatly reduce the specific conductance of molten Cu_2S, and 50 mol pct of CuCl reduces the conductance from 77 to about 5 ohm^{-1} cm^{-1}. This is close to the value[7] for pure molten CuCl or, indeed, most ionically conducting salts. The points at compositions rich in CuCl were obtained by extrapolation from specific conductance data taken at lower temperatures, because the volatility of CuCl is too great to permit measurement at 1200°C. This extrapolation does not endanger the interpretation of Fig. 2, since the specific conductance of CuCl-rich melts is so small.

Electrolytic Cell Efficiency Measurements

Experimental Procedure—*Apparatus*: The current efficiency of electrolysis has been determined either from the gain at the cathode or the loss at the anode. The arrangements of the apparatus are described as follows.

For the measurement of cathode gain, the apparatus used is shown in Fig. 3. The cell consists of a graphite crucible with a smaller McDanel crucible sitting inside. The space inside the latter is the cathode compartment and the annular space between is the anode compartment. Communication between these compartments is made through a small hole located about 1 in. from the bottom of the apparatus. The inside of the graphite crucible is painted with Alundum cement, except for an area of ½ x ¼ in. 180° from the position facing the communication hole, which acts as the anode. The cathode is a graphite tube, one end closed, fitted closely on a quartz thermocouple well. It is also painted with Alundum cement except for its bottom, about 0.5 cm^2, which is the cathode surface. The cathode can be moved in and out of the

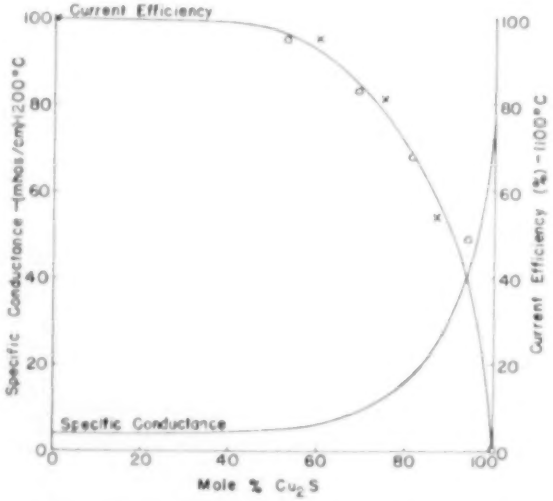

Fig. 2—Current efficiency and specific conductance curves for various compositions of Cu_2S-CuCl mixtures are plotted. Crosses represent current efficiency deduced from anode loss; circles, current efficiency deduced from cathode gain extrapolated to zero ionic current.

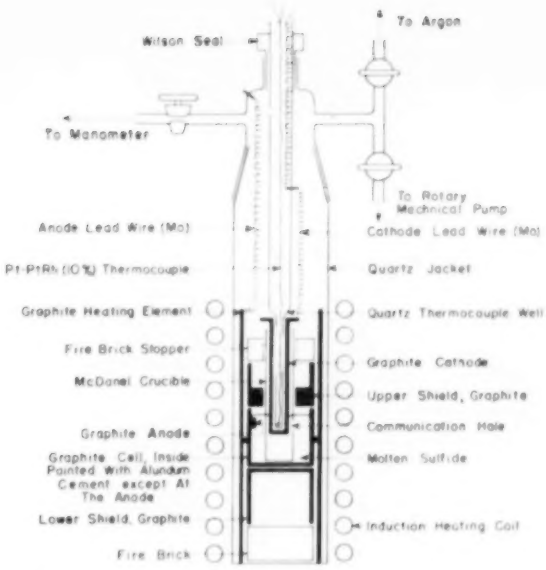

Fig. 3—Schematic diagram illustrates cell for measuring cathode gain.

molten sulfide through a Wilson seal at the top of the apparatus. The cell is surrounded with graphite shields at both the top and bottom, and sits inside a long graphite heater. This assembly provides uniform temperature, and insures against induction stirring in the cell. It is surrounded by a quartz jacket containing argon as a protecting atmosphere. Temperature of the cell is measured with a Pt—Pt-10 pct Rh thermocouple. To minimize any convection in the electrolyte, the temperature gradient of the cell is adjusted so that the top of the graphite crucible is about 10°C hotter than the bottom. The temperature of the electrolyte is maintained manually to within ±10°C during the run.

In the case of the electrolysis of CuCl where a solid copper anode is used, the same arrangement shown in Fig. 3 is used, except that the graphite crucible now acts as the cathode and the graphite tube attached to the quartz thermocouple well is replaced by a piece of solid copper. A resistance furnace is used instead of high frequency induction heating.

For the measurement of anode loss, the arrangement shown in Fig. 4 is used. Its operation is self-explanatory.

Procedures: The experimental procedures consist of the following steps:

1) Prefusion of the Sample—The Cu_2S, CuS, and CuCl used are of chemically pure grade and in the form of fine powder. The FeS used is of technical grade and in the form of small lumps. The Cu_2S is prefused in a graphite crucible in a static dry argon atmosphere at 1250°C for 1 hr, then crushed to small pieces. After removing the visible copper beads, the prefused mass is found to contain 80.3 to 81.5 pct Cu. Further heating under the same conditions produces little change in composition. The CuCl is prefused in Pyrex glass tubes at 500°C in a static dry argon atmosphere in the presence of copper. The product is yellowish-white and contains 64.4 pct Cu. The FeS is prefused in the same way as Cu_2S, and the product contains 64.3 pct Fe. Cu_2S samples containing 15 wt pct CuS or 5.9 to 46.4 mol pct CuCl are made by mixing the calculated amounts of the ingredients, melting them in a static dry argon atmosphere, and maintaining them for 1 hr at 1150°C for homogenization.

2) Blank Run—In the electrolysis, all of the observed cathode gain or anode loss may not be due to the electrochemical reactions at the electrodes. Thermal decomposition of the electrolyte, the non-equivalent loss of its components due to the difference in their volatility, and the dissolution of the electrodes in the electrolyte may also contribute to the change at the electrodes. A blank run without current is therefore made for the same period of time and under the same conditions as used in the electrolysis. The results are used for the correction of the changes observed at the electrodes in the electrolysis.

3) Electrolysis—The cell is charged with the desired electrolyte, and the system is evacuated and flushed a few times with dry argon gas. The electrolyte is then melted in a static dry argon atmosphere and brought to the desired temperature. For the measurement of the cathode gain, the graphite cathode is lowered into the molten electrolyte. After the predetermined amount of current has been passed, as measured with a copper coulometer, the cell is cooled down quickly, and the contents of the two electrode compartments analyzed. The composition of the electrolyte near the communication hole between the two compartments is also analyzed to make sure that no mixing of the contents of the two compartments has occurred during the electrolysis. To measure the anode loss, the same procedures are followed except that it is the anode which is lowered into the electrolyte. After the electrolysis, the anode is lifted out of the elec-

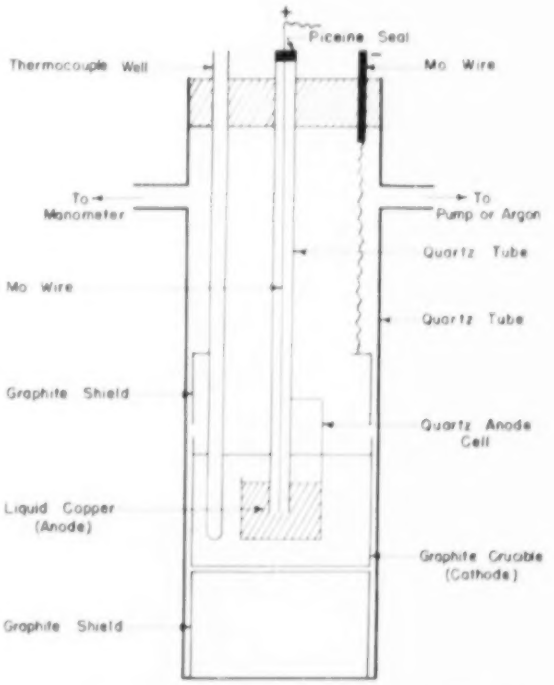

Fig. 4—Schematic arrangement for measuring anode loss using liquid copper anode is illustrated.

Table I. Current Efficiency in Electrolyzing Molten Cu_2S with Various Additions Deduced from Cathode Gain*

Sample	Temperature, °C	Time of Electrolysis, Min	Current, Amp	Weight of Cathode Part, G	Copper Content of Cathode Part, Pct: After Blank Run, Copper	After Blank Run, Iron	After Electrolysis, Copper	After Electrolysis, Iron	Current Efficiency, Pct
Cu_2S; 80.3 pct Cu	1250	127	5.75	17.1	80.5	—	80.6	—	0
	1300	142	5.25	4.52	80.8	—	80.7	—	0
Cu_2S + 50 wt pct FeS; 40.6 pct Cu, 31.4 pct Fe	1150	125	6.50	4.73	40.6	31.7	40.0	31.8	0
	1250	150	6.20	5.12	40.9	31.7	40.7	32.0	0
FeS; 64.3 pct Fe	1250	132	6.10	4.41	—	64.7	—	64.8	0
Cu_2S + 15 wt pct CuS; 78.1 pct Cu	1160	127	4.70	4.92	79.8	—	80.5	—	0.7
	1130	125	4.75	4.84	79.5	—	80.6	—	1.1
	1180	145	4.90	5.10	79.7	—	80.9	—	1.1
Cu_2S + CuCl; 5.9 mol pct CuCl†	1100	60	1.50	4.70	79.9	—	84.1	—	27.7
			0.50	5.22	79.9	—	81.7	—	39.3
			0.20	4.75	79.9	—	80.8	—	44.6
			—	—	—	—	—	—	49‡
Cu_2S + CuCl; 19.6 mol pct CuCl†	1100	40	1.50	4.51	78.6	—	83.1	—	50.0
			0.50	4.74	78.6	—	80.5	—	53.3
			0.30	5.32	78.6	—	79.7	—	57.6
			—	—	—	—	—	—	67‡
Cu_2S + CuCl; 30.3 mol pct CuCl†	1100	60	1.50	4.95	77.5	—	86.5	—	55.8
			0.50	5.60	77.5	—	80.9	—	69.1
			0.20	5.11	77.5	—	79.1	—	76.6
			—	—	—	—	—	—	83‡
Cu_2S + CuCl; 40.4 mol pct CuCl†	1100	30	1.50	5.10	75.1	—	81.4	—	72.3
			0.50	5.52	75.1	—	77.3	—	82.3
			0.30	4.84	75.1	—	76.7	—	87.3
			—	—	—	—	—	—	95‡

* The cathode is graphite; area, 0.3 cm^2.
† Since CuCl is highly volatile, some of the CuCl in the mixture is lost during the run. The composition given is the mean value of the initial composition and that at the end of the blank run.
‡ Current efficiency is obtained by extrapolating the current efficiencies at the given CuCl concentration to zero ionic current. Ionic current equals the total current times the corresponding current efficiency.

trolyte and cooled. The anode is separated as completely as possible from the attached electrolyte, weighed, and both the metal and the attached electrolyte are analyzed.

4) Calculation of the Current Efficiency—To calculate the current efficiency from the cathode gain, the following method is used: Suppose the material in the cathode compartment after the electrolysis weighs w_s g and consists of w_{Cu} g Cu deposited at the cathode and $(w_s - w_{Cu})$ g of electrolyte. If analysis after electrolysis shows that this material contains a wt pct Cu while the result of the blank run is a' pct, then $(w_s - w_{Cu})\ a'/100$ is the copper content of the electrolyte and $(w_s - w_{Cu})\ a'/100 + w_{Cu}$ is the total copper content of this material after electrolysis. The latter divided by w_s is equal to $a/100$, the weight fraction of copper in the cathode section after electrolysis, i.e.

$$\frac{(w_s - w_{Cu})\ a'/100 + w_{Cu}}{w_s} = a/100 \qquad [2]$$

or $w_{Cu} = \dfrac{w_s\,(a - a')}{(100 - a')}$ and the current efficiency $= p = \dfrac{w_s\,(a - a')}{(100 - a')QM_{Cu}}$ where Q is the amount of current passed through the electrolyte in Faradays, and M_{Cu} is the equivalent weight of Cu^+, assuming none of the current is carried by Cu^{++}. To calculate the current efficiency from the anode loss, the change in weight of the anode due to electrolysis is divided by the amount of current passed in Faradays and the equivalent weight of Cu^+.

Electrolytic Cell Efficiency Measurements

Experimental Results—The results obtained are shown in Tables I and II, which can be summarized as follows:

1) Results obtained from cathode gain, Table I, indicate that molten Cu_2S, FeS, and Cu_2S + 50 wt pct FeS conduct exclusively by electrons. The amount of ionic conduction in these melts, if any, is beyond the sensitivity of this method, which is about the order of 1 or 2 pct.

2) Addition of 15 wt pct CuS to Cu_2S introduces a small amount of electrolysis, ~1 pct, to the melt as shown by the results obtained from cathode gain, Table I. However, owing to the decomposition of CuS to Cu_2S at high temperature and the reaction of CuS with deposited copper to form Cu_2S, this value can only be considered as a lower limit. Attempts have been made to determine the current

Table II. Current Efficiency in Electrolyzing Mixtures of Cu_2S + CuCl and Pure CuCl Deduced from Anode Loss*

Sample	Temperature, °C	Time of Electrolysis, Min.	Current, Amp	Net Copper Loss at Anode, G	Current Efficiency, Pct	
Cu_2S + CuCl, 13.1 mol pct CuCl†	1100°C	20	0.20	0.088	55.3	53.7
	1100°C	20	1.00	0.415	52.1	
Cu_2S + CuCl, 24.4 mol pct CuCl†	1100°C	20	0.20	0.132	83.0	82.1
	1100°C	20	1.00	0.645	81.2	
Cu_2S + CuCl, 40.3 mol pct CuCl†	1100°C	30	0.20	0.148	93.3	94.2
	1100°C	20	1.00	0.756	95.1	
CuCl	450°C	25	0.25	0.254	102	
	500°C	30	0.25	0.307	103	
	500°C	30	0.25	0.302	102	

* For Cu_2S + CuCl mixtures, the anode is liquid copper, area, 0.3 cm^2; and the cathode is graphite; area, 26 cm^2. For CuCl, the anode is solid copper, area, 0.5 cm^2; and the cathode is graphite, area, 0.5 cm^2.
†This is the mean value of the initial composition and final composition of the blank run. See preceding footnote.

efficiency from the weight loss of liquid copper anodes. However, because of the rapid reaction between Cu^{++} in the melt and the liquid copper anodes, the weight loss in the blank run is comparable to the total weight loss in the electrolysis run. For example, 20 min electrolysis at 3 amp (liquid copper anode area = 0.3 cm^2) and 1100°C produces an anode loss of 0.704 g Cu, and the corresponding blank run involves a loss of 0.612 g Cu. The accuracy was, therefore, very poor, and the results not strictly reproducible. However, in all of the measurements made, the current efficiency was less than 10 pct.

3) Current efficiencies measured by both the cathode gain and the anode loss, Tables I and II, show that the addition of a small amount of CuCl to Cu_2S produces a large amount of electrolysis in the melt, and that the mixture becomes almost a pure ionic conductor at a CuCl concentration equal to 50 mol pct. For a given CuCl concentration, the current efficiencies deduced from anode weight loss are independent of the anode current density, 0.7 to 3.3 amp per cm^2. See Table II. However, the current efficiencies deduced from cathode gain decrease with the increase of the current density. See Table I. If the results are extrapolated to zero ionic current, the values of current efficiency obtained for different CuCl concentrations are found to fit fairly well the same current efficiency vs CuCl concentration curve as the current efficiencies deduced from anode loss. This agreement gives considerable weight to the data. The curve is shown in Fig. 2 together with the *specific conductance vs CuCl concentration* curve.

The decrease of the cathode current efficiency with the increase of current density is probably caused by the development of concentration polarization at the anode at high current densities owing to the large size of the Cl^- and the $S^=$ and, therefore, the slow rate of replenishment of the Cl^- and/or the $S^=$ lost at the anode. The concentration polarization developed favors the conductance of electrons, decreasing the current efficiency.

4) Results obtained from anode weight loss indicate that molten CuCl, 450° to 500°C, shows a cell efficiency of 100 pct with, essentially, no component of electronic conduction. It is obviously an ionic conductor.

Discussion of Results

It is evident from these data that addition of chloride ion destroys the electronic conduction of the molten Cu_2S. Since the partial conductance of each conducting species in a system is directly proportional to its number and its mobility, the observed facts indicate that the added CuCl must have caused a decrease in the number and/or mobility of the conducting electrons, and probably an increase in the number and/or mobility of the conducting ions in these melts. Considering the apparently complete destruction of electronic conduction by chloride addition, it seems likely that the effect on conduction is not entirely due to lowering of electronic mobility through simple scattering of the conductance electrons by chloride ion. In fact, the plot of electronic resistivity vs CuCl concentration given in Fig. 5 does show that the flexion is opposite in sign to that found for simple scattering in solid alloys.[‡] Further, the electronic conductance of molten Cu_2S-CuCl does not follow either of the two principal types of compositional dependencies observed in molten binary alloys: rule of mixtures, as in molten Sn-Pb,[4] or a catenary behavior, as in molten Na-K,[5] and in many solid, isomorphous binary alloys.[6]

[‡] This is not an unambiguous argument against simple scattering as the cause of decrease in specific conductance, because the scattering effect might be entirely different in this case of an ionic solute.

[†] Molten Cu_2S-FeS also follows a rule of mixtures relationship.[3]

Tentatively, the view is taken that the structure of molten Cu_2S consists of a solution of Cu^+ and $S^=$ ions, with the $S^=$ ions bound together by weak covalent bonds into a loose network. It is thought that these weak covalent bonds are the source of the semiconduction in molten Cu_2S as explained in the following. It is believed that addition of chloride ion destroys the weak covalent bonds between sulfide ions and renders the system entirely ionic.

Electrical phenomena are well explained in the case of solids by the band approximation,[10] which

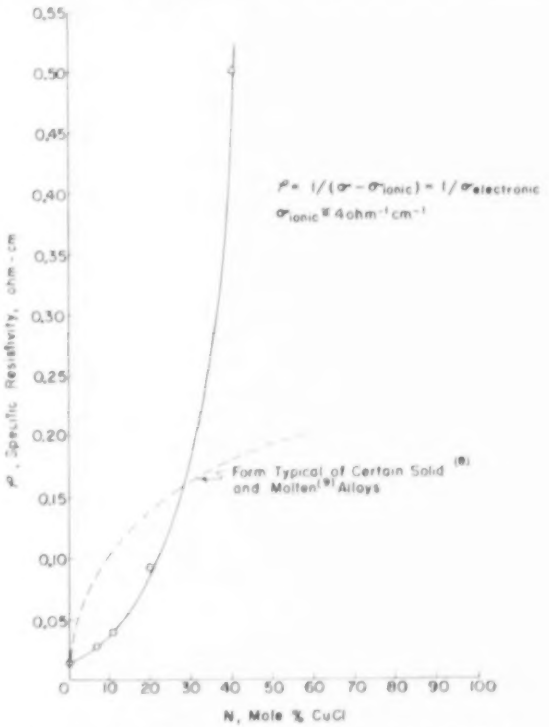

Fig. 5—Graph plots electronic resistivity vs mol pct CuCl in Cu_2S molten at 1200°C.

is difficult to extend to liquids because it assumes long range order in the structure. Although no comparable theory has been established for the liquid state, it is instructive to interpret the electrical behavior of molten Cu_2S in terms of energy level diagrams. Fig. 6 gives the proposed diagrams for the energy levels of valence and conduction band electrons in molten Cu_2S. It is seen in Fig. 6a that stoichiometric Cu_2S is represented as an intrinsic semiconductor. This simplifying assumption is made in spite of the fact that stoichiometric solid Cu_2S exhibits *p*-type semiconduction at room temperature.[11]

Upon heating, some electrons are raised by thermal energy from the valence band across the gap or forbidden zone to the conduction band, and serve to increase the electronic conduction. Fig. 6b represents the present case of slightly desulfurized Cu_2S specimens. The excess copper atoms act as electron

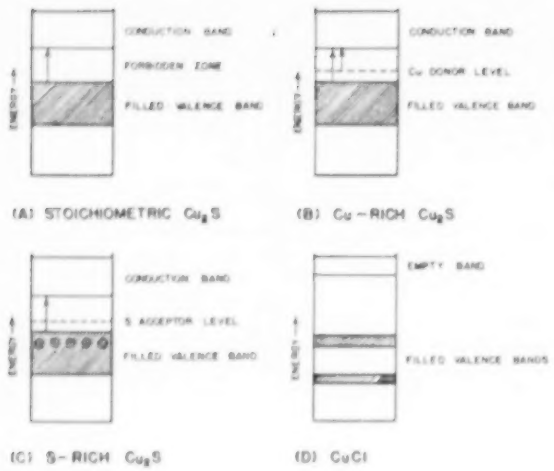

Fig. 6—Proposed energy level diagrams are shown for electrons in molten sulfides and S-Cl mixtures.

donors and establish a discontinuous, occupied impurity level in the forbidden zone. Because less thermal energy must be supplied to elevate these electrons into the conduction band, they contribute a component of *n*-type semiconduction which is additive to the intrinsic semiconduction. However, if the copper donor level is in the lower portion of the forbidden zone, it would not enhance conduction appreciably.

Fig. 6c represents the expected situation in sulfur-rich Cu_2S specimens. The excess sulfur atoms act as electron acceptors, establishing a discontinuous, unoccupied impurity level in the lower portion of the forbidden zone. Electrons from the valence band are promoted to these impurity levels, leaving mobile, positive holes in the valence band, thus contributing a component of p-type semiconduction.

As CuCl is added to the Cu_2S, the band structure of the liquid is radically changed. Fig. 6d gives the typical ionic band structure resulting from addition of sufficient CuCl to the Cu_2S. The energy gap between filled and unfilled bands is too great to permit semiconduction.

It must be pointed out that although the results fail to show the existence of ionic conduction in molten Cu_2S, Cu_2S + 50 wt pct FeS, and FeS, they do not exclude the possibility of some ionic character in these materials. In fact, as pointed out by Jost,[12] there exists no sharp boundary between ionic and electronic conductors. The observed results depend on the sensitivity of the experimental methods and the relative magnitude of the partial conductance by electrons and by ions. Most measurements of the diffusion coefficients in liquids are of the order of 10^{-5} cm^2 per sec. Assuming the validity of the Einstein-Nernst equation and all the migration to be ionic, it can be shown that the upper limit of the partial ionic conductance corresponding to a diffusivity of the order of 10^{-5} cm^2 per sec is of the order of 1 ohm^{-1} cm^{-1}. If that is the case with the melts in this work, then for Cu_2S at 1250°C (σ = 80 ohm^{-1} cm^{-1}) and FeS at 1250°C (σ = 1500 ohm^{-1} cm^{-1}), the partial ionic conductances are about 1 pct and 0.1 pct, respectively, putting them on or below the borderline of the sensitivity of the methods used here.

More critical experiments are required to test and evaluate these ideas quantitatively. It should be remembered that the sulfide systems under discussion were somewhat desulfurized. Systems having the stoichiometric ratio of copper or iron to sulfur might behave somewhat differently.

Acknowledgments

The authors are indebted to Mrs. G. Osuch for experimental assistance and to W. R. Bitler of the Carnegie Institute of Technology, Physics Dept., for helpful discussions of theory. The research described in this paper was sponsored by the U. S. AEC under Contract No. AT(30-1)-1024.

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Technical Note

Strain Aging of AISI 4340

by H. W. Paxton and C. C. Busby

IT has been shown previously[1] that strain aging can markedly improve the tensile properties of low carbon martensites, especially the yield-tensile ratio, without seriously affecting the ductility. In view of interest in high strength steels, an investigation has been made of the effect of strain aging following tension or rolling on the tensile properties of AISI 4340 in an attempt to obtain a tensile

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strength of 260,000 psi with a yield-tensile ratio of about 0.95.

After a preliminary investigation, ½ in. sq blanks were cut longitudinally from a commercial 7 in. sq billet of AISI 4340. These were normalized after 1 hr at 1650°F in a controlled atmosphere.

The tensile specimens were then rough machined to 1/16 in. oversize. These oversize specimens were fully quenched in oil after they had been austenitized for 1 hr at 1550°F, tempered for 1 hr at 600°F (giving Rc 46 to 48), and machined to final shape (0.252 in. diam with a 1 in. gage length). Specimens for rolling were quenched as blanks and tempered.

The early parts of the stress-strain curves were automatically recorded to give 0.01, 0.1, and 0.2 pct yield strengths. Only 0.1 pct yield strengths are recorded here. Some trouble was experienced with extensometer slippage on these hard materials. This appears to be a general problem.

Strain was introduced prior to aging by one of two methods. Extensions up to 3 pct were produced in simple tension, or a reduction in thickness of 1 pct of a quenched and tempered blank was obtained by rolling. Following the tensile strain, the specimens were aged for 1, 2, 4, and 8 hr at 212°, 302°, 392°, and 572°F. The rolled specimens were heated for 8 hr at 212° or 15 hr at 392°F before final machining of the specimen.

Fig. 1 shows diagrammatically the strain-aging process. Curve I is for the unaged material; curve II shows the stress-strain curve of a material prestressed to Y_p, giving a strain of ϵ_p before aging.

In the quenched and tempered condition, the properties were: T_o, tensile strength of 252,000 psi; Y_o, yield strength (0.1 pct) of 219,000 psi; 13 pct elongation; and 44 pct reduction in area.

The results of the specimens given a tensile prestrain are summarized in Fig. 2. The lower curve

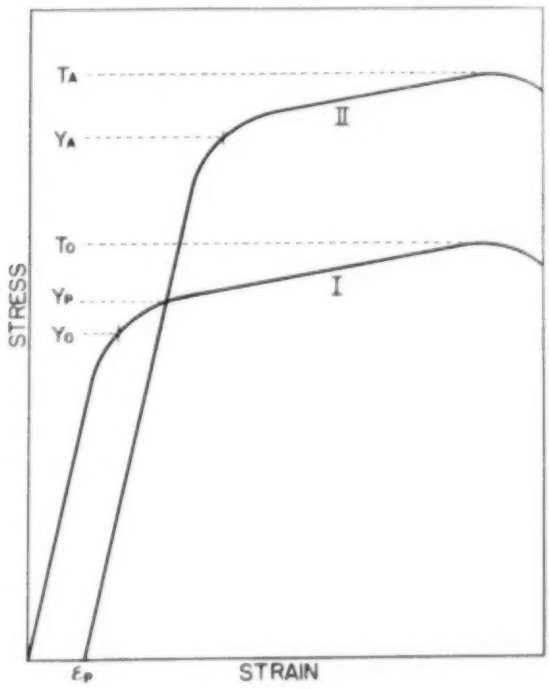

Fig. 1—Diagrammatic representation of strain aging process used.

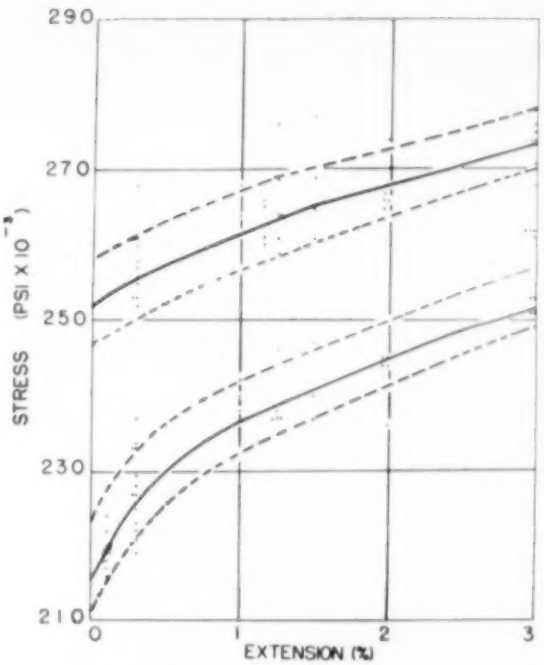

Fig. 2—Dots on upper curve are T_o, representing tensile strength after prestrain ϵ_p, shown on abscissa. Y_s are not shown because of large scatter. Dots on lower curve are Y_p for various ϵ_p, giving an average stress-strain curve for the material.

is the stress-strain curve for the unaged material. The upper band gives the tensile strengths after prestraining the amount indicated on the abscissa followed by aging. No effect of time and temperature of aging was observed except at 212°F for times of 2 hr and less. Here the full amount of aging had not occurred.

Fig. 2 does not show the scatter in yield-tensile ratio caused by variations in Y_s. The value of this ratio varied from 0.93 to 1.00 in the experiments conducted. The higher figure may be of doubtful value in practice, although adequate ductility is still present (elongation of 9 to 12 pct and about 40 pct reduction in area).

Results on specimens deformed by rolling were much more reproducible. After 15 hr at 392°F, the yield-tensile ratio was much more consistent in the range 0.93 to 0.96, with ductility similar to the foregoing figures. This appears to be a satisfactory method of achieving the previously stated goal. Further work is proceeding to investigate more fully the effects of rolling.

Attempts to interpret the source of the strain aging from theoretical considerations have not yet proved fruitful.

Acknowledgment

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Effect of Carbon on Some Properties of Ti-Mo Alloys

The influence of carbon on tensile strength, tensile ductility, transformation kinetics, and grain growth characteristics of selected Ti-Mo base alloys was studied. No systematic influence of carbon in tensile strength or significant deleterious effect on tensile ductility was observed. There was a marked increase in transformation rate due to carbon. Dispersed carbides exert a marked inhibiting effect on grain boundary migration, and thus effectively prevent grain coarsening during solution treatment in the β phase field.

by D. W. Levinson, W. Rostoker, and A. Yamamoto

AS part of a research program directed toward the illumination of factors governing modes of transformation, transformation kinetics, and mechanical properties obtainable through these transformations by heat treatment, Ti-Mo base alloys were selected for study. The binary system is a characteristic phase diagram type which has been studied in some detail[1, 2] in relation to transformation kinetics and mechanical properties.

Although carbon bearing alloys have acquired a bad reputation, the possibilities of melting titanium under conditions which occasion some carbon pick-up are very attractive. It is therefore of considerable importance to know whether carbon, present as a dispersed carbide phase, is actually deleterious when all other detrimental factors are minimized.

Basic alloy compositions containing nominally 3, 5, 7, and 11 pct Mo were prepared with systematic carbon addition up to 1 pct by weight. Various of these alloys were subjected to a series of critical and definitive experiments to delineate the effect of carbon on the transformation behavior and associated mechanical properties.

Experimental Procedure

Alloys were prepared from 115 Bhn magnesium-reduced sponge titanium. This sponge analyzed approximately 0.05 pct C. Ti-Mo and Ti-C master alloys were made by arc-melting the sponge with high purity (99.9+ pct) molybdenum and spectroscopic grade graphite, respectively. Alloys were then prepared from the master alloys and sponge by double arc-melting. One kg ingots were prepared by melting in a nonconsumable electrode furnace. These ingots were forged at 1000°C to ½ in. rods, and cleaned and processed into electrodes for the second melting operation. The final ingots were ground to remove surface defects, then forged again to ½ in. or ⅜ in. diam rods for processing to test samples. It is significant that all of the alloys at all carbon levels forged satisfactorily. For convenience, the alloys will be referred to throughout the text by their nominal analyses.

Samples for the study of transformation rates were prepared from ½ in. diam round stock. They were then solution treated in a helium filled tube furnace at 1000°C for 30 min prior to the isothermal transformation treatments in lead bath furnaces. Temperature control in both cases was within ±3°C. Following the isothermal transformation treatments the samples were water quenched. These experiments were carried out before the general adoption of the resistometric procedure for kinetic studies. The data were therefore obtained entirely by metallographic analysis. M_s temperature was also determined by the metallographic method.

Shoulder-type tensile test pieces were machined from heat treated, ½ in. diam slugs to provide a 0.252 in. test diam and a 1 in. gage length. The isothermal-type heat treatments were chosen from previous data[2] to provide three levels of strength and ductility.

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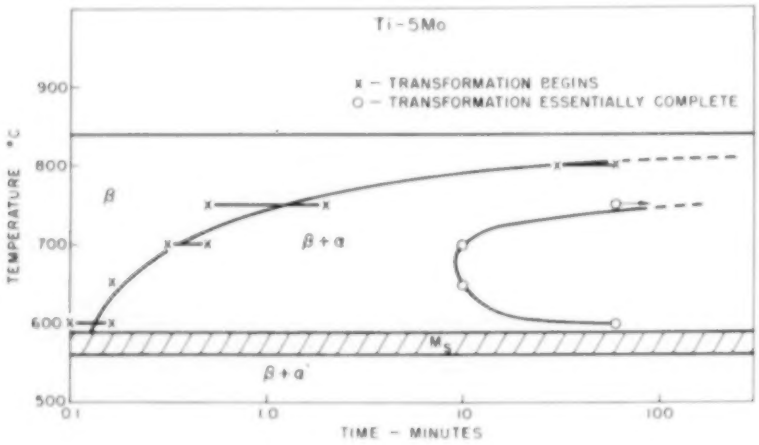

Fig. 1—*TTT* curve for Ti-5.16 pct Mo alloy is plotted.

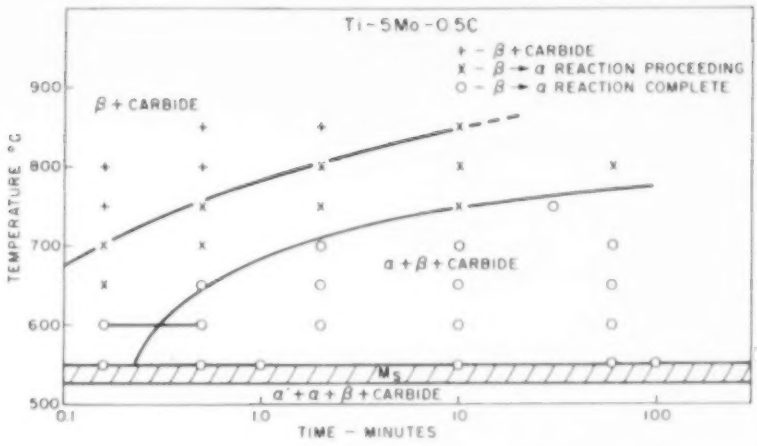

Fig. 2—*TTT* curve for Ti-5.21 Mo-0.46 pct C alloy is plotted.

The grain growth studies were carried out on disks approximately ¼ in. thick cut from ⅜ in. round stock. The heat treatments for these studies were carried out in evacuated Vycor bulbs at temperatures in the β field ranging between 800° and 1200°C for times up to 24 hr. These samples, too, were water quenched from the temperature of study. Grain sizes were determined by lineal analysis of representative micrographs made at exactly X100. The grain sizes reported are β grain sizes. In spite of the fact that the more dilute alloys transform to α' on quenching, the grain sizes of the parent β phase could be easily inferred from the obvious disposition of the α' colonies. These samples were electropolished for study. It was found that the values reported could be reproduced within ±10 pct by independent measurement of another print.

Effect of Carbon on the Transformation Kinetics

The results of the metallographic study of transformation rates of the carbon bearing and carbon-free Ti-5 pct Mo alloy are summarized in the *TTT* curves of Figs. 1 and 2.

Fig. 1, the *TTT* curve for the carbon-free alloys, shows the range of uncertainty concerning the beginning of the rejection of α, as designated by the spread between data points. The open circles represent transformation times beyond which no significant change in microstructure was evident.

Little is known about phase relationships in the ternary system Ti-Mo-C.[5] Examination of the Ti-5 pct Mo-0.5 pct C alloy showed fine nodular carbide uniformly dispersed in a matrix of either β or β + transformation products, depending on the heat treatment. In all cases, it appeared as though the carbide took no part in any of the solid state reactions. So far as can be discerned metallographically, the isothermal decomposition characteristics

Table I. Tensile Properties of Ti-3 Pct Mo Alloys with Carbon Additions

Alloy	Heat Treatment	Ultimate Strength, Psi	Reduction in Area, Pct	Elongation, Pct
Ti-3.06Mo	1000°C, 30 min; water quenched	116,600	14.5	6.0
Ti-3.78Mo-0.40C		142,000	15.1	6.0
Ti-3.33Mo-0.65C		132,000	31.1	8.0
Ti-3.27Mo-0.60C		125,000	3.8	3.0
Ti-3.33Mo-0.73C		135,200	16.5	5.0
Ti-3.06Mo	1000°C, 30 min; water quenched	92,300	55.4	31.0
Ti-3.78Mo-0.40C	700°C, 30 min; water quenched	101,800	29.1	15.0
Ti-3.33Mo-0.65C		106,200	46.0	22.0
Ti-3.27Mo-0.60C		99,600	42.3	18.0
Ti-3.33Mo-0.73C		112,200	21.3	21.0
Ti-3.06Mo	1000°C, 30 min; water quenched	107,200	44.2	22.0
Ti-3.78Mo-0.40C	650°C, 5 min; water quenched	107,300	21.7	17.0
Ti-3.33Mo-0.65C		104,100	44.2	19.0
Ti-3.27Mo-0.60C		104,400	12.2	9.0
Ti-3.33Mo-0.73C		113,200	25.1	13.0

Table II. Tensile Properties of Ti-7 Pct Mo Alloys with Carbon Additions

Alloy	Heat Treatment	Ultimate Strength, Psi	Reduction in Area, Pct	Elongation, Pct
Ti-7.07Mo	1000°C, 30 min; water quenched	115,400	71.3	33.0
Ti-7.07Mo-0.38C		115,400	36.3	23.0
Ti-7.02Mo-0.33C		121,000	33.7	22.0
Ti-7.89Mo-0.67C		114,800	11.0	9.5
Ti-6.89Mo-0.83C		122,700	25.7	18.0
Ti-7.07Mo	1000°C, 30 min; water quenched	104,400	38.8	24.0
Ti-7.07Mo-0.38C	650°C, 30 min; water quenched	107,600	50.0	22.0
Ti-7.02Mo-0.33C		114,100	39.4	16.0
Ti-7.89Mo-0.67C		115,200	20.9	10.0
Ti-6.89Mo-0.83C		119,000	34.3	14.0
Ti-7.07Mo	1000°C, 30 min; water quenched	165,800	4.6	4.0
Ti-7.07Mo-0.38C	550°C, 60 min; water quenched	169,800	5.4	10.0
Ti-7.02Mo-0.33C		171,800	13.7	6.0
Ti-7.89Mo-0.67C		171,400	10.6	7.0
Ti-6.89Mo-0.83C		164,100	1.4	2.0

Table III. Tensile Properties of Ti-11 Pct Mo Alloys with Carbon Additions

Alloy	Treatment	Ultimate Strength, Psi	Reduction in Area, Pct	Elongation, Pct
Ti-10.17Mo	1000°C, 30 min; water quenched	121,000	21.7	5.0
Ti-11.20Mo-0.16C		107,400	15.9	19.0
Ti-10.54Mo-0.25C		129,200	25.7	10.0
Ti-10.26Mo-0.31C		124,800	16.7	6.0
Ti-11.65Mo-0.42C		135,200	33.1	11.0
Ti-11.52Mo-0.69C		149,200	13.7	4.0
Ti-10.90Mo-1.08C		127,600	16.7	1.0
Ti-10.17Mo	1000°C, 30 min; water quenched	155,200	7.6	4.0
Ti-11.20Mo-0.16C	600°C, 15 min; water quenched	194,000	3.8	3.0
Ti-10.54Mo-0.25C		161,000	13.1	6.5
Ti-10.26Mo-0.31C		143,000	24.3	9.0
Ti-11.65Mo-0.42C		143,200	26.5	10.0
Ti-11.52Mo-0.69C		143,000	15.3	6.0
Ti-10.90Mo-1.08C		141,000	10.6	13.0
Ti-10.17Mo	1000°C, 30 min; water quenched	189,400	3.8	3.0
Ti-11.20Mo-0.16C	500°C, 15 min; water quenched	156,800	10.6	7.0
Ti-10.54Mo-0.25C		198,000	6.2	3.0
Ti-10.26Mo-0.31C		191,400	4.6	3.0
Ti-11.65Mo-0.42C		177,200	8.4	3.0
Ti-11.52Mo-0.69C		178,000	16.7	10.0
Ti-10.90Mo-1.08C		172,600	6.2	3.0

are identical to the binary alloy with the same molybdenum content except, of course, for the carbide particles which are always present in the ternary alloy.

On the *TTT* curve for the Ti-5 pct Mo-0.5 pct C alloy, Fig. 2, the upper equilibrium temperature for the β + carbide/$\beta + \alpha$ + carbide boundary is not precisely known, but appears to be about 875°C. Since its location is uncertain, it was not shown on the chart. Water quenched structures verified the existence of only the β and carbide phases at the 1000°C solution treatment temperature.

A comparison of the *TTT* charts for the Ti-Mo and Ti-Mo-C alloys shows the strong accelerating influence on reaction rates imposed by the carbon addition. That this is not associated with nucleation by the carbide particles can be appreciated by examination of Fig. 3. This micrograph shows the rejection of α beginning, mostly, in the β grain boundaries. The presence of the carbide phase indicates the β solid solution is saturated with carbon.

The presence of different interstitial solutes (oxygen and nitrogen) has been shown[4, 5] to accelerate the decomposition of β titanium. As is pointed out, this effect is usually associated with a subgrain structure, not evident in similar materials free of the interstitial solute. This subgrain structure is, in fact, well delineated by the first α to precipitate. The occurrence of a subgrain structure was not marked in the case of the carbon addition studied here, nor in the case of carbon additions to Ti-Mn alloys.[4] However, the grain size of the carbon-bearing and carbon-free Ti-Mo alloy studied here differed very considerably. The carbides inhibited the normal grain coarsening tendency, and the accelerated decomposition is most probably at least partly caused by the higher nucleation probability associated with a larger relative grain boundary volume. Though not conclusively demonstrated by these experiments, there is a good possibility that carbon in solid solution by itself also affects the transformation rate, since the M_s temperature is lowered by approximately 50°C by the carbon addition. This cannot be rationalized in terms of grain size.

Table IV. Average Grain Diameter, Mm, After Heat Treatment Indicated for Ti-3 Pct Mo Base Alloys

Temperature, °C	Time, Hr	Carbon Free	Nominal Carbon Content, Wt Pct 0.25	0.50	0.75	1.00
880	1	0.10	0.04	0.04	0.05	0.05
	3	0.28	0.04	0.04	0.07	0.04
	8	0.17	0.04	0.06	0.04	0.04
	16	0.15	0.04	0.07	0.08	0.04
	24	0.48	0.07	0.06	0.07	0.08
980	1	0.33	0.07	0.07	0.04	0.04
	3	0.36	0.07	0.07	0.06	0.06
	8	0.34	0.08	0.10	0.09	0.08
	16	0.43	0.08	0.12	0.08	0.07
	24	0.85	0.09	0.10	0.12	0.07
1080	1	0.38	0.08	0.10	0.06	0.08
	3	0.39	0.09	0.14	0.06	0.06
	8	0.35	0.08	0.09	0.06	0.05
	16	0.38	0.11	0.14	0.09	0.06
	24	0.42	0.10	0.16	0.10	0.08

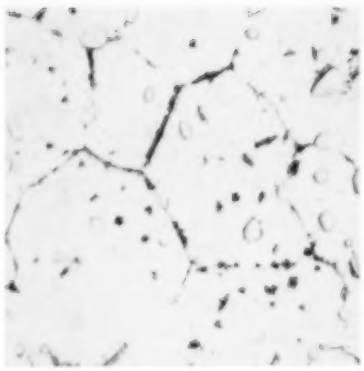

Fig. 3—Microstructure shows Ti-5.21 pct Mo-0.46 pct C alloy transformed at 750°C for 30 sec. Rejected α is not associated with carbide phase, but appears to be nucleating normally, i.e., mostly in the grain boundaries of the β. Specimen was etched with glycol-HF-HNO_3 etch. X500. Area reduced approximately 30 pct for reproduction.

Mechanical Properties of Ti-Mo-C Alloys

The data summarizing the experimental phase of this work concerned with mechanical properties are the average values of at least two tests, and are presented in Tables I, II, and III. Values obtained agreed, with two exceptions, within ±10 pct of those reported. The heat treatments selected constitute essentially complete transformations. In

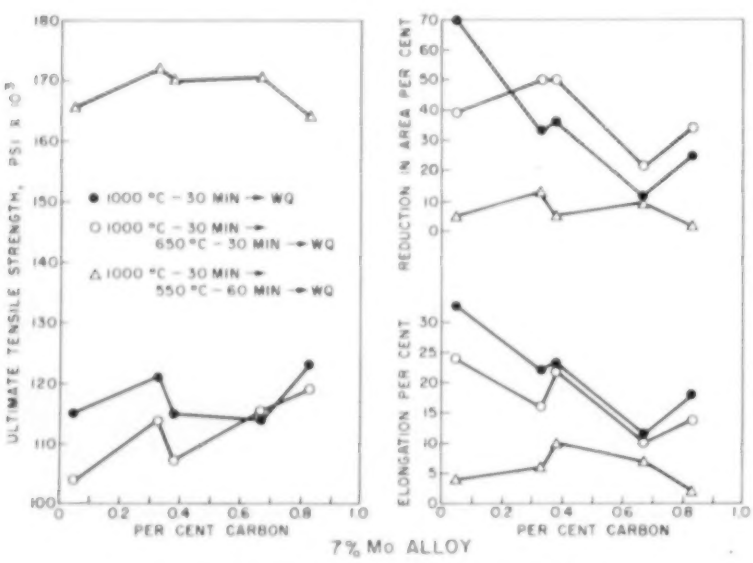
ULTIMATE TENSILE STRENGTH, PSI x 10³
● 1000 °C – 30 MIN → WQ
○ 1000 °C – 30 MIN → 650 °C – 30 MIN → WQ
△ 1000 °C – 30 MIN → 550 °C – 60 MIN → WQ
PER CENT CARBON
REDUCTION IN AREA PER CENT
ELONGATION PER CENT
PER CENT CARBON
7% Mo ALLOY

Fig. 4—Tensile data for Ti-7 pct Mo base alloys are plotted.

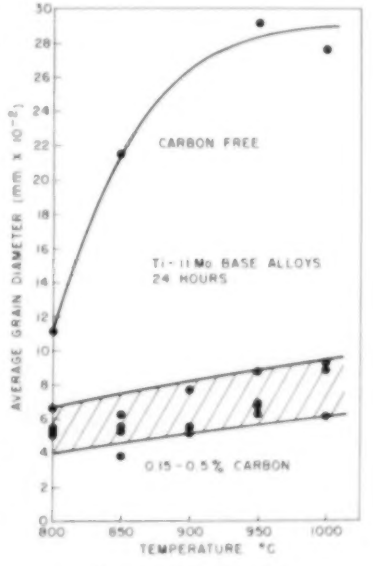

Fig. 5—Data are plotted for 24 hr grain growth of Ti-11 pct Mo base alloys.

order to illustrate the trends, the data for the Ti-7 pct Mo base alloys are plotted on Fig. 4. The points, solid circles, open circles, and triangles indicate particular heat treatments, as shown.

The Ti-7 pct Mo base alloys were selected, since only in this case was a trend clearly evident. It is significant that the tendency for dispersed carbides to reduce tensile ductility is small and, like the effect on ultimate tensile strength, not well defined. Quite reasonable combinations of strength and ductility are maintained at even the highest carbon level.

Table V. Average Grain Diameter, Mm, After Heat Treatment Indicated for Ti-7 Pct Mo Base Alloys

Temperature, °C	Time, Hr	Carbon Free	Nominal Carbon Content, Wt Pct			
			0.25	0.50	0.75	1.00
840	1	0.18	0.08	0.09	0.04	0.04
	3	0.19	0.04	0.08	0.05	0.04
	8	0.14	0.04	0.06	0.04	0.04
	16	0.20	0.08	0.04	0.04	0.04
	24	0.24	0.10	0.07	0.08	0.07
940	1	0.22	0.14	0.10	0.09	0.04
	3	0.33	0.08	0.09	0.07	0.07
	8	0.41	0.10	0.13	0.12	0.04
	16	0.42	0.11	0.12	0.10	0.04
	24	0.36	0.09	0.08	0.08	0.07
1040	1	0.32	0.10	0.11	0.09	0.09
	3	0.27	0.17	0.13	0.08	0.08
	8	0.33	0.14	0.11	0.08	0.06
	16	0.38	0.11	0.14	0.09	0.08
	24	0.39	0.16	0.13	0.10	0.09
1140	1	0.34	0.12	0.09	0.04	0.04
	3	0.33	0.10	0.07	0.06	0.05
	8	0.54	0.19	0.09	0.06	0.08
	16	0.75	0.11	0.11	0.08	0.08
	24	0.49	0.23	0.15	0.09	0.10

Grain Growth Characteristics of Ti-Mo-C Alloys

The results of the grain size study are presented in Tables IV, V, and VI, and the data for the 24 hr heat treatment of the Ti-11 pct Mo base alloys are plotted in Fig. 5.

Table VI. Average Grain Diameter, Mm, After Heat Treatment Indicated for Ti-11 Pct Mo Base Alloys

Temperature, °C	Time, Hr	Carbon Free	Nominal Carbon Content, Wt Pct			
			0.15	0.20	0.25	0.50
800	1	0.11	0.04	0.04	0.04	0.06
	3	0.10	0.05	0.04	0.08	0.06
	8	0.10	0.04	0.04	0.06	0.06
	16	0.10	0.04	0.05	0.06	0.08
	24	0.11	0.05	0.07	0.05	0.06
850	1	0.10	0.05	0.06	0.05	0.05
	3	0.10	0.04	0.05	0.08	0.04
	8	0.13	0.05	0.05	0.05	0.05
	16	0.13	0.06	0.06	0.05	0.05
	24	0.22	0.05	0.05	0.06	0.04
900	1	0.13	0.05	0.05	0.06	0.06
	3	0.23	0.06	0.05	0.06	0.04
	8	0.20	0.06	0.07	0.06	0.04
	16	0.30	0.06	0.06	0.06	0.05
	24	0.26	0.05	0.06	0.08	0.05
950	1	0.14	0.05	0.05	0.06	0.07
	3	0.17	0.07	0.06	0.06	0.06
	8	0.24	0.08	0.06	0.06	0.06
	16	0.32	0.06	0.08	0.06	0.07
	24	0.29	0.07	0.06	0.07	0.09
1000	1	0.29	0.06	0.07	0.06	0.08
	3	0.22	0.08	0.08	0.07	0.07
	8	0.25	0.07	0.07	0.07	0.07
	16	0.26	0.11	0.09	0.06	0.08
	24	0.28	0.09	0.07	0.06	0.09

The inhibition of grain coarsening by the dispersed carbides is very pronounced. Data for the various carbon levels are plotted in Fig. 5 as a band, since there is no clear cut dependence of the grain size on carbon contents after these heat treatments. All of the samples contained a large enough number of dispersed carbide particles to inhibit grain boundary migration with the same order of magnitude of effectiveness. Grain sizes smaller by factors of from 5 to 10 are observed in most cases on the composition range studied when comparing carbon-bearing to carbon-free alloys subjected to the same thermal cycle.

Summary

The influence of carbon on the transformation kinetics, mechanical properties, and grain growth characteristics of some Ti-Mo alloys was investigated.

A marked acceleration of the rate of rejection of α from β on isothermal transformation was observed. This increase in rate is similar to that observed for alloys of this type containing oxygen or nitrogen in solid solution. Because in the present alloy studied the solid solution was saturated with carbon, and the presence of the carbide phase inhibited grain growth, the simultaneous contributions of both the carbon in solution and the much finer grain size to increased transformation rates were observed.

No systematic effect of carbon on the ultimate tensile strength of the alloys studied was observed. In some instances, the ultimate tensile strength of the carbon-containing alloy was lower than for the carbon-free alloy given the same heat treatment. More frequently, the ultimate tensile strength of the carbon-containing alloys would be slightly higher. The differences were usually very small. In no case were differences of more than 20 pct observed. It is particularly significant that tensile ductility is not reduced to below usable levels by the presence of carbon at any carbon level in the range studied.

The heat treatments were not intended to evaluate the entire range of properties obtainable in these alloys, but corresponded to different strength levels and good and poor tensile ductility in carbon-free material. Heat treatments were selected which consisted of essentially complete transformations. This was done so that the change in transformation kinetics associated with the presence of carbon would not produce differently constituted test samples because of the particular times chosen. Since isothermal transformation times were adequate in all cases to transform the carbon-free composition completely, there was no doubt that the more rapidly transforming carbon-bearing alloys would be also completely transformed.

Dispersed carbides exert a marked inhibiting effect on the grain coarsening tendency of these alloys solution treated in the β field. Grain sizes smaller by factors of 5 to 10 are observed in even the lowest carbon—0.15 wt pct—alloy studied compared to the carbon-free composition subjected to the same thermal cycle.

Acknowledgment

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A Kinetic Study of the Leaching of Molybdenite

A study of the rate of dissolution of molybdenite (MoS_2) in alkaline solution was carried out under carefully controlled conditions. Effects of temperature, oxygen over-pressure, and KOH concentration were evaluated. Studies were made in the temperature range 100°C to 175°C and in the pressure range 0 to 700 psia of oxygen. Under these conditions molybdenite was found to leach according to a linear mechanism. Both oxygen over-pressure and KOH concentration were found to control the rate of leaching. The mechanism has been explained in terms of adsorption of oxygen at the molybdenite surface followed by configurational rearrangement of the adsorbed molecules. The hydroxyl ion dependency is believed to be diffusion-controlled. Laboratory batch studies have shown that molybdenite can be readily dissolved in alkaline solutions under moderate conditions of temperature and pressure. Commercial application of this process to the production of ferro-molybdenum and molybdenum chemicals is promising in view of the ease of dissolution of molybdenite and the relatively noncorrosive conditions involved in the process.

by William H. Dresher, Milton E. Wadsworth, and W. Martin Fassell, Jr.

HIGH temperature-high pressure techniques have long been used to great advantage in the organic chemical industry, the petroleum industry, and the paper industry. Only recently, however, have these methods been used to extract metals from their ores on a commercial scale. The Chemical Construction Corp., together with interested producers of nickel and cobalt, has done much to develop methods of producing nickel and cobalt powders by the use of high temperature-high pressure techniques.[1] The Howe Sound Co. is currently operating a plant near Salt Lake City in which the new Chemical Construction Corp. technique is applied to cobalt-arsenic sulfide concentrates. In this method the concentrates are leached in a dilute solution of sulfuric acid under air pressure at a high temperature. Near Edmonton, in Alberta, Canada, the Sherritt Gordon Co. is also using the new method in conjunction with its ammoniacal leach process.[2] National Lead Co., at Fredricktown, Mo., is operating a process similar to that of Howe Sound.

In spite of the rapid growth of high temperature-high pressure hydrometallurgical processes, there has been very little work done on fundamental principles involved in this type of process. Consequently the literature lacks any significant data in this field. Oxidation of pyrite,[3] sphalerite,[4] galena,[5] and recently molybdenite[6] in alkaline solutions has been reported to some extent.

This investigation was initiated, therefore, to broaden the application of high temperature-high pressure hydrometallurgy and also to contribute some insight into the basic mechanisms of oxidation in an aqueous medium under these conditions. In addition to the immediate consequences of these processes much valuable information remains to be learned about fundamental reactions when they are carried out at temperatures and pressures slightly higher than those normally encountered.

Leaching of molybdenite by alkaline solutions under oxygen pressure has recently been reported in the Russian literature by E. S. Usataya,[6] who found that leaching rate increased with an increase in the pH of the solution—the strongest effects being observed at a pH of 10—and also with an increase in temperature. Usataya also has reported the formation of a protective film on the surface of the molybdenite when the leaching solution was weakly alkaline, neutral, or acidic. He believes that this oxidation process explains the migration of Mo^{++} in the oxidation zones of molybdenite ore deposits and the subsequent impoverishment of the ores.

Equipment: The high temperature-high pressure reaction unit used in this work was especially designed for kinetic studies of this nature, emphasis being placed on accuracy of measurement and precision of control. As details of the unit's construction and operation have been discussed elsewhere,[7] only basic features and principles of operation will be discussed at this point.

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TP 4243BD. Manuscript, Sept. 14, 1955. New York Meeting, February 1956.

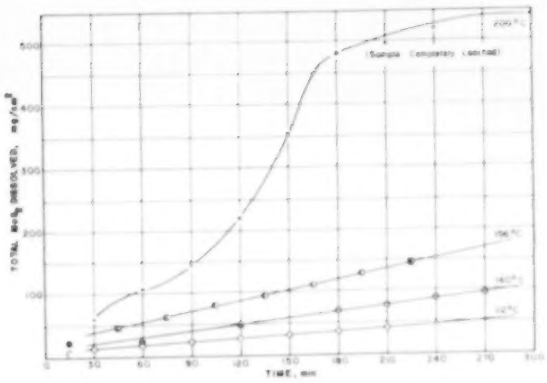

Fig. 1—Typical rate curves.

1) Temperature of the solution within the autoclave is constantly measured, recorded, and controlled.

2) Gas over-pressure of the system is constantly regulated and indicated.

3) Provisions are made for lowering a sample into the reaction zone of the autoclave once thermal equilibrium has been attained.

4) A means is provided for removal of liquid samples from the reaction zone of the autoclave during the course of the reaction without disrupting operation of the unit.

Solubility of oxygen in various concentrations of solutions used in this experiment was measured in equipment adapted from that described by Frolich, et al.[9] and by Ipatieff and Monroe.[9] The oxygen-saturated solution from the autoclave was admitted to the gas-measuring equipment by means of a water-cooled capillary tube. A vacuum-tight connection was made between the capillary tube and the flash chamber of the gas-measuring equipment. The liquid was measured by a standard 100-ml capacity burette encased in a water jacket, and the volume of gas was measured in a Fisher precision gas burette.

Bench-scale tests were made in an Autoclave Engineers 1-gal, electrically heated autoclave. A Leeds and Northrup type C Micromax controller was used to control temperature of the solution within the autoclave.

Experimental Procedure: Molybdenum sulfide used in the kinetic study was Molysulfide lubricant, Grade 2, a commercial product manufactured by Climax Molybdenum Co. The MoS_2 content of this material was better than 99 pct. A less pure grade of molybdenite, obtained from the Kennecott Copper Co., was used for the bench-scale tests. This material contained approximately 89 pct MoS_2, the remainder being a siliceous gangue material.

Solid molybdenite samples, 0.650 in. diam and approximately 0.085 in. thick, were prepared by pressing the powdered molybdenite (97 pct, —100 mesh) in a Carboloy die at a pressure of approximately 85 tons per sq in. These samples varied from 91 to 92 pct of theoretical density of massive molybdenite. The geometric surface area of the molybdenite disk was calculated from micrometer measurements of the sample. After preparation, the molybdenite disks were pressed by hand into an Inconel sample holder and mounted in the autoclave. Flat, plate-like samples were used in these studies in order to maintain the geometric surface area essentially constant during the course of the run. Rate curves for the dissolution of MoS_2 powders were found to deviate from linearity because of the large variation in surface area as the reaction progressed.

Molybdenum content of the leach solution, measured at periodic intervals, was determined spectrophotometrically from a phenylhydrazine hydrochloride-molybdenum complex by a Beckman Model DU quartz spectrophotometer. The method of analysis followed that developed by Ayres and Tuffly.[10]

Measurements of oxygen solubility in the leach solutions were made with the equipment previously described. Since a relatively large volume of solution was required for each solubility measurement, it was not possible to measure solubility concurrently with molybdenum concentration. When a solubility measurement was made, the solution within the autoclave was brought to the desired temperature and the oxygen over-pressure was increased in increments of 100 to 200 psi. A measurement of the amount of oxygen dissolved in 50 ml of the leach solution was determined for each increment. Each measurement consisted of a reading of the volumes of both liquid and gas, of the temperature of the gas in the burette, and of the atmospheric pressure. Results of these measurements were expressed in mols of oxygen per liter of solution. Solubility measurements were made for all temperatures and KOH concentrations used in the leaching studies.

Batch studies on leaching molybdenite were carried out in the Autoclave Engineers 1-gal autoclave. In this series of studies, potassium hydroxide solution and powdered molybdenite were charged to the

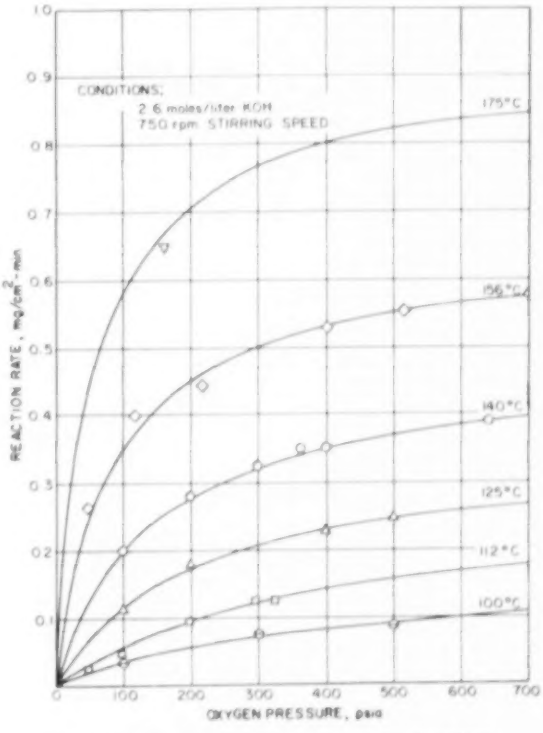

Fig. 2—Effect of oxygen over-pressure on rate of leaching.

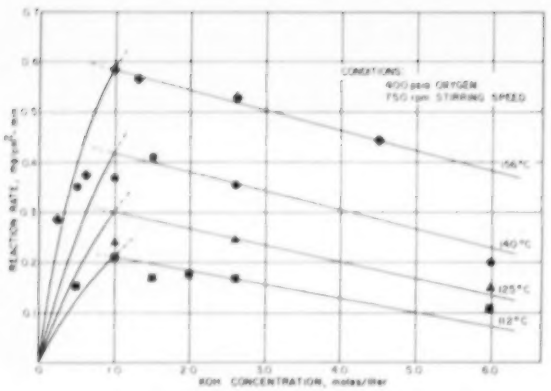

Fig. 3—Effect of KOH concentration on rate of leaching.

autoclave, which was evacuated and allowed to come to operating temperature without agitation. Oxygen was admitted to the autoclave to the desired working pressure and agitation started. Samples of the solution were withdrawn at intervals by means of a capillary tube. Due to the high molybdenum concentration of the solution the progress of the reaction was followed by titrating the KOH remaining in the solution rather than by the colorimetric method of analysis used in the kinetic study.

Experimental Results: The reaction rate data consisted of measurements of the rate of formation of MoO_4^{--} under the various conditions of leaching. Results to be described are based on the leaching of more than 65 samples of molybdenite in potassium hydroxide solution under oxygen partial pressure of 0 to 700 psia and at temperatures from 100°C to 175°C. As shown in Fig. 1, molybdenite was found to leach according to a linear mechanism under nearly all conditions investigated. When relatively high rates of reaction were involved, as in runs at 175°C or higher, deviation from linearity was observed. This deviation was found to be due to disintegration of the pressed samples and a subsequent increase in effective surface area.

Table I. Bench-Scale Tests of Molybdenite Leaching

Oxygen Pressure, Psia	Temperature, °C	Molar Ratio, MoS_2:KOH	Time to 95 Pct Completion, Min
200	156	1:2	62
400	156	1:2	38
600	156	1:2	33
800	156	1:2	29
1000	156	1:2	22
1500	156	1:2	17
400	108	1:2	110
400	125	1:2	85
400	140	1:2	65
400	156	1:2	38
400	175	1:2	23
400	156	1:4	28
400	156	1:3	38
400	156	4:5	46

Four variables were studied in determining kinetics of the leaching reaction: *speed of agitation, KOH concentration, temperature,* and *oxygen overpressure.* Rate of the reaction was grossly affected by speed of agitation below approximately 500 rpm. Above this speed, however, reaction rate was relatively stable until cavitation occurred at about 1000 rpm and the sample disk was no longer covered by the leach solution. Stirring rate was maintained at 750 rpm for all tests. Fig. 2 shows the experimental rates of leaching for various pressures of oxygen, Fig. 3 the effect of a change in the leachant concentration on the rate of leaching for several different temperatures.

A series of bench-scale tests were carried out to demonstrate commercial feasibility of the leaching process. Optimum conditions were taken from the results of the kinetic studies and briefly studied batchwise. Oxygen over-pressure, temperature, and various molar ratios of MoS_2 to KOH were studied. Results of these tests, expressed as the time required to leach 95 pct of the molybdenite, are presented in Table I.

Tests similar to those presented for KOH solution were carried out in NaOH and Na_2CO_3 solutions. The reaction was found to proceed using each of these reagents. The rate measured in Na_2CO_3 solutions was much slower because of the buffering action of Na_2CO_3 and the resulting lower hydroxyl ion concentration. Use of sodium salts produces Na_2MoO_4, which is less soluble than K_2MoO_4—115.5 g per 100 ml at 100°C for Na_2MoO_4 as compared to 184.6 g per 100 ml at 25°C for K_2MoO_4.

Discussion of Results

The linear reaction rates observed for all experiments, Fig. 1, carried out within the range of the conditions of this study indicate that the surface is not hindered by products of the reaction. Any build-up of adherent surface layers as a result of the reaction would result in nonlinear rate curves. The linearity of the rate curves also indicates that the concentration of surface sites that contribute to the reaction remains constant for any given set of conditions.

The overall measured rate is clearly a function of the oxygen over-pressure, as is shown in Fig. 2. The shape of this curve suggests a surface adsorption process that reaches a maximum rate for complete surface coverage. The oxygen dependency curves are regular and typical of a process involving adsorption of a gas onto a surface. Hydroxyl ion dependency, however, is not so simple. The isotherms in Fig. 3 can be divided into two regions. In the first region, below a concentration of approximately 1.0 mols per liter, the reaction rate is an increasing function of the hydroxyl ion concentration. Above this region the rate decreases with increasing hydroxyl ion concentration. This rather strange shape of the KOH dependency may be attributed to three major effects: 1) the concentration of oxygen dissolved in the solution varies with the KOH concentration for any given over-pressure, 2) the activity coefficient of KOH varies considerably over the range of concentrations of KOH considered, and 3) the combined effect of diffusion and viscosity must be taken into consideration. To eliminate the first of these effects the solubility of oxygen in KOH solutions must be known. Since the literature lacks data obtained under the conditions of this study these measurements were made experimentally. Fig. 4 shows the solubility of oxygen in KOH solutions under the conditions employed in each of the leaching studies. The quantity S/P is the ratio of solubility of oxygen in mols per liter to the absolute pressure of oxygen over the solution. Activity coefficients of the various concentrations of KOH solutions were taken from data of Harned and Cook[13]

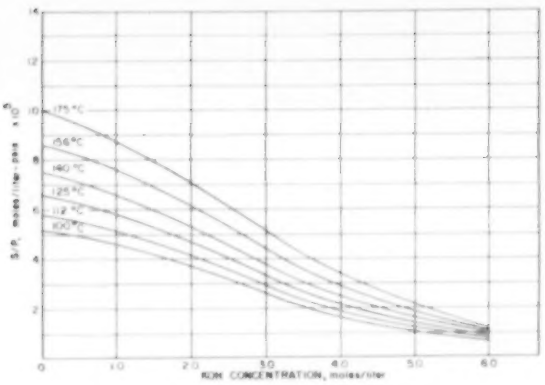

Fig. 4—Solubility of oxygen in KOH solutions.

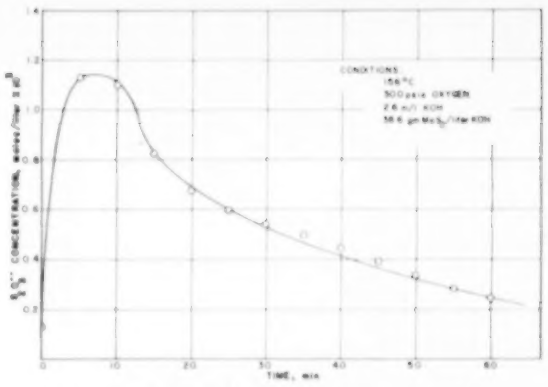

Fig. 5—Formation of $S_2O_3^{--}$ during leaching of MoS_2.

and extrapolated to the desired temperatures. Since the concentrations of oxygen in solution were so low—10^{-3} mols per liter—activity coefficients of the oxygen dissolved in the KOH solutions were assumed to be equal to unity.

The overall reaction may be explained stoichiometrically by Eq. 1:

$$MoS_2 + 9/2O_2 + 6OH^- \rightarrow MoO_4^{--} + 2SO_4^{--} + 3H_2O. \quad [1]$$

After complete oxidation the end products were the molybdate and the sulfate ions. If, however, the solutions were analyzed as soon as they were removed from the autoclave and the molybdenum sulfide was not completely reacted, the sulfur was found to be present in solution as the sulfate ion plus a measurable quantity of the thiosulfate ion —$S_2O_3^{--}$. This was determined by a standard iodine titration. Fig. 5 is a typical plot of $S_2O_3^{--}$ ion concentration vs time. The presence of the thiosulfate ion in reactions of this type has been reported previously by Forward et al.,[12] who found curves of this type for the dissolution of cobalt, nickel, and copper sulfides in ammoniacal solutions. They also noted the presence of dithionate ion and the higher thionates as well as sulfamate. However, thionates cannot exist for any appreciable time in alkaline solutions in the absence of the ammonia ion due to their decomposition by the hydroxyl ion resulting in the formation of thiosulfate ion.[13] The direct formation of the thiosulfate ion may be represented by the intermediate overall reaction

$$MoS_2 + 5/2O_2 + 4OH^- \rightarrow MoO_4^{--} + S_2O_3^{--} + 2H_2O. \quad [2]$$

The complexity of these reactions (Eqs. 1, 2) requires a series of reactions, of which one or more may be rate-controlling. In any event, it appears that the surface reactions involved result in intermediate compounds that must be capable of forming the observed end products and at the same time maintain the proper oxygen and charge balance.

Theoretical

Development of the Rate Equation: According to the Absolute Reaction Rate Theory,[14] the rate of any chemical reaction may be represented by the general equation

$$\text{Rate} = \sum_j \pi_{ij} c_{ij} k'_j = \sum_j \kappa \frac{kT}{h} \pi_{ij} c_{ij} e^{-\Delta F_j^+/RT} \quad [3]$$

where $\sum_j$ represents the summation of all contributing rates, $\pi_{ij} c_{ij}$ represents the product of the reactant concentrations for the j^{th} rate step, k'_j is the specific rate constant, κ is the transmission coefficient, ΔF^+_j is the activation energy of the j^{th} rate step and k and h are the Boltzman and Planck constants, respectively. Application of Eq. 3 requires evaluation of the rate-contributing steps involved as well as evaluation of the reactant concentrations $\pi_{ij} c_{ij}$ for each step.

The following steps are suggested as possibly leading to the overall reaction commensurate with the measured rates and the observed end products:

$$MoS_2 + O_2 \rightarrow MoS_2 \ldots O_2 \quad \text{(fast)} \quad [4]$$

$$MoS_2 \ldots O_2 + O_2 \underset{k_2}{\overset{k_1}{\rightleftharpoons}} MoS_2 \ldots 2O_2 \quad \text{(slow)} \quad [5]$$

$$MoS_2 \ldots 2O_2 \xrightarrow{k_3} \left[MoS_2 \ldots 2O_2 \right]_{act} \quad \text{(slow)} \quad [6]$$

$$\left[MoS_2 \ldots 2O_2 \right]_{act} + OH^- \rightarrow MoO_2(OH)^- + S_2O_3^{--} \quad \text{(fast)} \quad [7]$$

$$MoO_2(OH)^- + OH^- \rightarrow MoO_4^{--} + 2H^+ \quad \text{(fast)} \quad [8]$$

$$H^+ + OH^- \rightarrow H_2O \quad \text{(fast)} \quad [9]$$

$$S_2O_3^{--} + 1/2\,O_2 \rightarrow S_2O_3^{--} \quad \text{(fast)} \quad [10]$$

An alternate mechanism would involve adsorption of a single molecule of O_2 as in Eq. 4 and the subsequent formation of S_2^{--} in Eq. 7.

The symbol | is used to denote a surface site or product of reaction at the surface. Electrical neutrality must of course be maintained by the presence of gegen ions of the proper charge. It is not intended in these reactions to indicate how oxygen is adsorbed on the active site. The character of the curves of Fig. 2 indicates molecular adsorption. This does not necessarily imply physical adsorption, since the molecular oxygen may possibly split on the sulfur

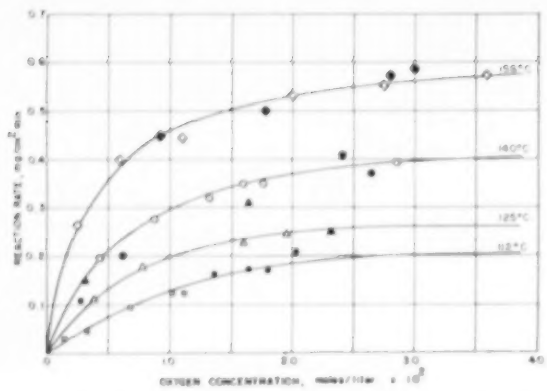

Fig. 6—Demonstration of the independence of KOH concentration.

or in some way split between the surface molybdenum and the sulfur. Kinetically, such splitting will appear as molecular adsorption. Eq. 6 represents a step in which the adsorbed oxygen undergoes a configurational change creating an active site prone to the action of the hydroxyl ion. The molybdenum oxy-hydroxide ion, $MoO_2(OH)^+$, proposed in Eq. 7 is not unlikely, since molybdenum oxy-sulfate, $MoO_2(SO_4)$, and MoO^{++}, are known.[10] The intermediate thiosulfite ion, $S_2O_2^{--}$, or perhaps 2 SO^-, provides a proper step in terms of oxygen and charge balance to explain the end products observed. These two intermediates would be very unstable and would react immediately at or near the surface according to Eq. 10. The final presence of sulfate ion, SO_4^{--}, results from further oxidation of thiosulfate in basic solution according to the reaction

$$S_2O_3^{--} + 2\,O_2 + 2\,OH \rightarrow 2\,SO_4^{--} + H_2O. \quad [11]$$

The addition of this reaction results in Eq. 1.

The present development is based upon a steady-state treatment in which the concentration of surface reactant is considered to be constant for any one set of conditions. These data may be treated in a similar fashion by considering surface equilibrium for adsorption of oxygen. Arguments will be presented, however, which indicate that equilibrium was not attained. If the fraction of total available sites covered with oxygen is considered (i.e., $MoS_2 \ldots 2O_2$ sites) as θ, under the steady-state treatment rate of formation of the $MoS_2 \ldots 2O_2$ sites is just balanced at the rate at which they disappear.[10] Accordingly, from Eqs. 5 and 6

$$\frac{d\theta}{dt} = k_a(1-\theta)\,[O_2]\,k_1 - \theta k_2 k_3 - \theta k_a k_b = 0. \quad [12]$$

The quantity $(1-\theta)$ represents the fraction of the available surface present as $MoS_2 \ldots 2O_2$. This implies that reaction (Eq. 4) is so fast that the fraction of the available surface sites completely uncovered by oxygen (MoS_2) is negligible. The constant k_a contains the terms necessary to convert from surface coverage to the true surface concentration, surface roughness, and the fraction of the number of surface sites that are active. The constants k_1 and k_2 represent the specific reaction rate constants for the forward and the backward reaction, respectively, of Eq 5. The constant k_3 represents the specific reaction rate constant for the reaction of Eq. 6. From Eq. 12 the value of θ may be written in typical Langmuir form:

$$\theta = \frac{\dfrac{k_1}{k_2 + k_3}\left[O_2\right]}{1 + \dfrac{k_1}{k_2 + k_3}\left[O_2\right]}. \quad [13]$$

Rate of the reaction was experimentally determined by the rate of the appearance of MoO_4^{--} in solution. Since the reaction represented by Eq. 7 is very fast, the rate of formation of MoO_4^{--} is determined by the rate of formation of the intermediate $MoO_2(OH)^+$ according to Eq. 6. Therefore,

$$\text{Rate} = \frac{d(MoO_4^{--})}{dt} = k_a \theta\, k_3. \quad [14]$$

Combining Eqs. 13 and 14 results in Eq. 15:

$$\text{Rate} = \frac{k_a k_3 \dfrac{k_1}{k_2 + k_3}\left[O_2\right]}{1 + \dfrac{k_1}{k_2 + k_3}\left[O_2\right]} \quad [15]$$

which, at constant temperature, can be written as Eq. 16:

$$\text{Rate} = \frac{k_a k_b\,[O_2]}{1 + k_b\,[O_2]} \quad [16]$$

where $k_a = k_a k_3$ and $k_b = k_1/(k_2 + k_3)$. This represents the conditions of the tests presented in Fig. 2. Each curve was determined at constant temperature and at a constant KOH concentration of 2.6 mols per liter. Solid lines drawn through the experimen-

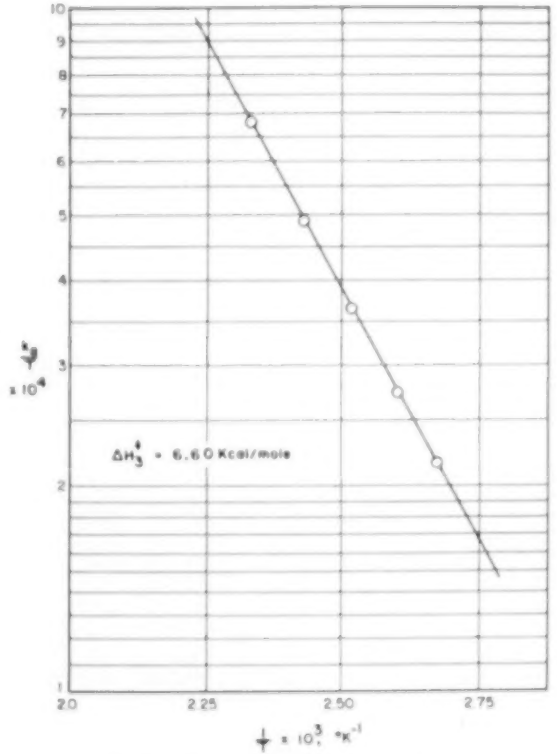

Fig. 7—Eyring plot for calculation of $\Delta H_3^{\ddagger}$.

tal points of Fig. 2 are the theoretical calculated curves according to Eq. 16. Plateau values of the curves represent complete surface coverage or $\theta \rightarrow 1$. These plateau values therefore represent the k_s terms at each temperature. From this and one other point on each curve the value of k_s may be determined for each isotherm according to Eq. 16. The term $k_s/(k_s + k_s)$ approaches the equilibrium constant K as k_s becomes small compared to k_s. Thus, $k_s \rightarrow K$ and then represents the equilibrium adsorption of oxygen in Eq. 5. From the curves of Fig. 2 the values of k_s were found to be 234, 300, 378, and 480 at the temperatures of 112°, 125°, 140°, and 156°C respectively. Since all surface adsorption processes must be exothermic, i.e., K must decrease with an increase in temperature, this increase in the value of k_s with temperature indicates that equilibrium was not attained. For this reason, the second alternative $k_s >> k_s$ must be chosen and the steady-state treatment adopted.

The effect of varying hydroxyl ion concentration is irregular from what might be expected. The curves of Fig. 3 were determined for various KOH concentrations at a constant over-pressure of oxygen of 400 psia and a constant stirring speed of 750 rpm. The concentration of oxygen dissolved in the KOH solution was not a constant due to the variation of the solubility of oxygen in the various concentrations of KOH, as indicated in Fig. 4. The effect of varying the hydroxyl ion concentration can be explained by considering the two sections of each of the isotherms separately. In the first section the solubility of oxygen in the dilute KOH solution is sufficient to supply an adequate amount of oxygen to the surface of the molybdenite in order to support the reaction. In this section, however, the hydroxyl ion does not diffuse to the surface fast enough to continue the reaction. Thus the rate of the reaction increases as the hydroxyl ion is increased. At a concentration of approximately 1.0 mols per liter the rate of supply of hydroxyl ion to the surface becomes equal to the rate of formation of active oxidized surface sites. Beyond this point, as the hydroxyl ion concentration continues to increase, oxygen solubility is limited to such an extent as to hinder the reaction by not supplying a sufficient amount of oxygen to maintain the oxidation reaction at an equal or faster rate than the reaction with the hydroxyl ion. In this section of the curves the rate thus becomes zero order with respect to KOH, since the overall rate now depends on the rate of formation of active oxidized surface sites which are removed by reaction with hydroxyl ion as soon as they are formed. The only hydroxyl dependency is manifest by the solubility of the oxygen in the KOH solution. This last point is clearly demonstrated by the fact that it is possible to intermix the experimental data of Fig. 2, determined at a constant KOH concentration of 2.6 mols per liter and at various oxygen over-pressures, with the hydroxyl ion independent data (above 1.0 mols per liter KOH) of Fig. 3 determined at various KOH concentrations and at a constant oxygen over-pressure of 400 psia. These data are shown in Fig. 6 where the rate of the reaction is plotted vs the concentration of oxygen dissolved in the KOH solutions. The data indicated by the open symbols are those obtained from Fig. 2; data indicated by the closed symbols are obtained from Fig. 3.

Thermodynamic Considerations: Using the steady-state treatment and the Absolute Reaction Rate Theory,

$$k_s = k_s k_s = k_s \exp\left[-\Delta F_s^{\ddagger}/RT\right] = k_s \exp\left[-\Delta H_s^{\ddagger}/RT\right] \exp\left[\Delta S_s^{\ddagger}/R\right]. \quad [17]$$

The slope of the Eyring plot of $\ln k_s/T$ vs $1/T$ should give the value of $\Delta H_s^{\ddagger}$. Fig. 7 represents such a plot, from which it was found that $\Delta H_s^{\ddagger}$ is equal to 6.60 kcal per mol. This represents the heat of activation for reaction (Eq. 6) which involves rearrangement of the adsorbed oxygen on the surface. Likewise, it can be shown that

$$k_s = \frac{k_1}{k_2} = \exp\left[-(\Delta F_1^{\ddagger} - \Delta F_s^{\ddagger})/RT\right] \quad [18]$$

$$= \exp[-(\Delta H_1^{\ddagger} - \Delta H_s^{\ddagger})/RT] \exp[(\Delta S_1^{\ddagger} - \Delta S_s^{\ddagger})/R].$$

The slope of the Eyring plot $\ln k_s$ vs $1/T$ gives a value of $\Delta H_1^{\ddagger} - \Delta H_s^{\ddagger}$. Fig. 8 shows that $\Delta H_1^{\ddagger} - \Delta H_s^{\ddagger}$ is equal to 5.24 kcal per mol. By difference, $\Delta H_1^{\ddagger}$ is found to be equal to 11.84 kcal per mol. This represents the heat of activation for adsorption of oxygen onto the surface of the molybdenite according to Eq. 5.

It is interesting to make an approximation of the number of surface sites actually involved in the leaching process. If a rate is selected where $\theta = 1$, Eq. 5 can be used to calculate k_s, which contains the factors: k_{ss}, surface roughness; $k_{s.r}$, the fraction of the total number of surface sites activated; and k', the geometric number of molecules per unit area of surface. Calculation of the number of MoS_2 sites on the principle cleavage plane of molybdenite—

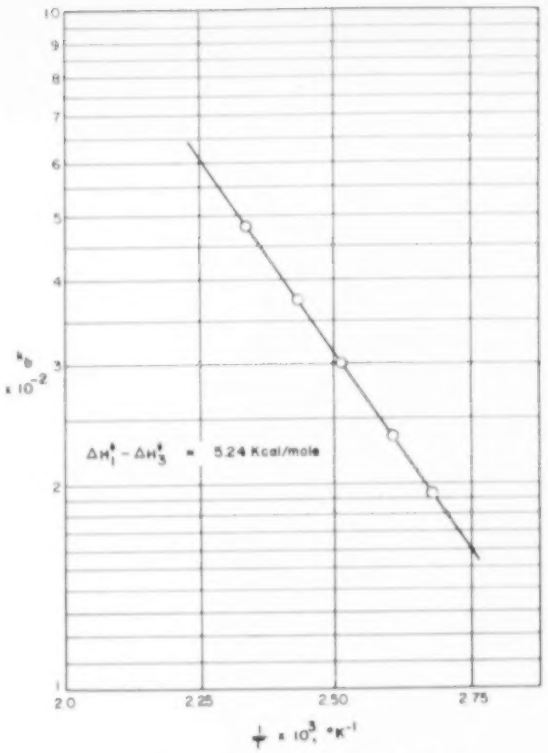

Fig. 8—Eyring plot for calculation of $\Delta H_1^{\ddagger} - \Delta H_s^{\ddagger}$.

the 0001 plane—gives the value of approximately 4.95×10^{-10} mols per cm^2. The difference in entropies $\Delta S_1^+ - \Delta S_2^+$ can be calculated from the relationship

$$\ln \frac{k_1}{k_2} = -\frac{(\Delta H_1^+ - \Delta H_2^+)}{RT} + \frac{(\Delta S_1^+ - \Delta S_2^+)}{R} . \quad [19]$$

This gives a value of 24.45 eu per mol. ΔS_1^+, the entropy change associated with the adsorption of oxygen onto the surface of the molybdenite, can be estimated by the use of the B.E.T. assumption that the energy of adsorption is approximately equal to the energy of liquifaction of adsorbed gas. The free energy of activation for each of the processes can be calculated by the thermodynamic relationship

$$\Delta F = \Delta H - T\Delta S . \quad [20]$$

Table II shows the percentage of active sites for several estimations of ΔS_1^+ calculated at the conditions: $T = 429°K$, $P = 400$ psia ($[O_2] = 2.0 \times 10^{-4}$ mols per liter), KOH = 2.6 mols per liter ($[a_{OH^-}] = 2.34$), and Rate = 0.530 mg per cm^2. min (3.33×10^{-10} mol per cm^2. sec). Values of $\Delta S_1^+ = -6.00$ eu per mol and $k_{SR} = 10$ may be selected as being nominal estimates of the entropy of adsorption and of the surface roughness factor. In this case, the number of active sites is approximately 0.26 pct of the number of total surface sites. This suggests that the face of a molybdenite platelet is relatively inactive and that the reaction probably occurs at the edges of these platelets, removing MoS_2 in a series of steps.

Table II. Estimation of the Number of Active Surface Sites

ΔS_1^+ Eu per Mol	ΔS_2^+ Eu per Mol	k_{ss} Mols Per Cm^2	$k_{SR}k_{ACT}$	Active Sites, Pct $k_{SR}=1$	Active Sites, Pct $k_{SR}=10$
0	−24.45	1.7×10^{-7}	3.4×10^{-4}	0.034	0.0034
−6.00	−30.45	1.3×10^{-6}	2.6×10^{-3}	2.6	0.26
−12.00	−36.45	7.9×10^{-6}	1.6×10^{-2}	16.0	1.60

Commercial Application

The product of the leaching process is a pregnant liquor carrying the desired molybdenum plus any other alkali-soluble metals that may have been present in the ore. Such a process, if applied to molybdenite ores containing appreciable quantities of rhenium, would result in a liquor containing potassium perrhenate as well as potassium molybdate. This liquor could then be treated by ion exchange or by solvent extraction to separate the rhenium from the molybdenum.

The sands flotation treatment in the molybdenum circuit, such as is currently used to separate molybdenum sulfide from the underflow of copper flotation circuits, could be eliminated by application of this process for dissolution of molybdenum. The depressed molybdenite plus the gangue material removed following the bulk sulfide step should be directly applicable to such a leaching process.

A novel application of this high temperature leach process has been devised in which use is made of waste pickle liquors to produce ferro-molybdenum for steel alloying. A feature of this process is the fact that the leachant can be recovered by treating the spent leach solution with hydrated lime. The calcium sulfate formed is filtered off, leaving the desired potassium hydroxide. The ferric molybdate produced by reaction between the pickle liquor and the leach liquor can be added to the steel melt directly or reduced to ferro-molybdenum in an electric furnace.

Conclusions

Molybdenum sulfide was found to leach readily in KOH solutions at relatively moderate oxygen pressure and temperature. The observed kinetics of the reaction can be explained by a steady-state analysis involving adsorption of oxygen at the surface followed by a configurational rearrangement of the oxygen on the surface. The oxidation product is then removed from the surface by a reaction with hydroxyl ion forming a water-soluble molybdate. The hydroxyl ion dependency is believed to be diffusion-controlled. A secondary hydroxyl ion dependency is due to a decrease in the solubility of oxygen in increasingly concentrated solutions of KOH. Heat of activation for adsorption of oxygen was found to be 11.84 kcal per mol. Heat of activation for the configuration change was found to be 6.60 kcal per mol. The small apparent number of active sites present suggests that the reaction occurs predominantly at the edges of the molybdenite platelets.

Although the process of high temperature leaching of molybdenite and some of its suggested applications may not be economically feasible at the present state of technology, it is felt that further application of such systems will produce a technique that will allow a process of this type to compete favorably with existing processes.

Acknowledgments

The authors express their appreciation to the Atomic Energy Commission for the funds that made this work possible and to the University of Utah Research Fund for funds for the equipment. Thanks are also extended to John R. Lewis, head of the Dept. of Metallurgy, for his support and interest in the work and to Noble M. Nerheim, graduate student, for work on the bench-scale studies.

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This paper represents a portion of the thesis to be submitted by William H. Dresher in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Utah.

Technical Note

Mechanism of Sulfate Formation During the Roasting Of Cuprous Sulfide

by C. L. McCabe and J. A. Morgan

IN the art of roasting sulfides it is well known that the lower the temperature and the higher the pressure of SO_x, the larger will be the amount of sulfate present in the product. However, the mechanism of sulfate formation is not generally understood. The following experiment* demonstrates in a direct way that, in the roasting of Cu_2S, the sulfate forms from the reaction of Cu_2O, formed by the oxidation of Cu_2S, with gaseous SO_2 (or SO_3) and O_2. Thus, the sulfate does not form at the sulfide surface. The reaction at the sulfide surface is the same whether or not sulfate is formed. Using an indirect method, Ong, Fassell, and Wadsworth[1] infer that sulfate forms after oxidation, during the roasting of sphalerite, agreeing with the observations of this paper. The method presented here of demonstrating that sulfate forms after formation of Cu_2O is to roast a sample of Cu_2S and then to locate and identify the phases formed.[2]

*Peretti[2] has reported observations similar to those in this note.

A solid cube of cuprous sulfide, made by melting Fisher reagent grade Cu_2S powder and measuring about 1.5 cm on edge, was placed on a Nichrome wire grid suspended over the top of an Alundum combustion boat. The assembly was placed in a tube furnace at 600°C and oxygen gas, flowing at 0.60 liters per min, was passed around the specimen for 24 hr. The furnace tube diameter was 1.5 in. The partially roasted sample was removed from the furnace and impregnated with resin No. BR 0014, obtained from the Palmer Products Co., and the impregnated sample was then mounted in Lucite. A cross section was obtained by grinding and the surface was prepared by the following steps: 1) grinding—60 grit, 3M disk, dry; 2) preliminary polishing—60 through 600 grit, 3M disk, dry; 3) polishing—8 μ diamond putty, silk cloth; and 4) final polishing—levigated magnesia in isopropyl alcohol, Selvyt cloth.

The color micrograph of the polished surface is shown in Fig. 1. The layers present in the micrograph are given along the side.

The compositions of the various layers were established by Debye-Scherrer patterns. From this evidence the following sequence of reactions which occur in the roasting of Cu_2S is inferred:

1) The oxidation of Cu_2S occurs with oxygen which has been transported through the oxide-sulfate layer by either gaseous or solid state diffusion. The products of this reaction at the Cu_2S surface are Cu_2O and SO_2.

2) The SO_2 diffuses out through the pores in the Cu_2O and finally reaches a position in the Cu_2O where the oxygen pressure and the SO_2 pressure have values such that the thermodynamic conditions for the formation of $CuSO_4$ are fulfilled. Then, the mixture of SO_2, SO_3 and oxygen reacts with the Cu_2O to form $CuSO_4$.

3) The $CuSO_4$ decomposes by the evolution of SO_3 or SO_2 and O_2, to form the basic sulfate. This is reasonable, since the SO_3 gradient will decrease toward the oxygen gas phase from the $CuSO_4$ layer.

4) For this same reason the basic sulfate will decompose to form CuO.

The above sequence of events is based on the assumption that diffusion through the oxide and sulfate layers, rather than the reaction at the sulfide-oxide interface, is rate-determining. This assumption is supported by the observation that these oxide and sulfate layers combined are almost nonpermeable to the flow of gases through them.

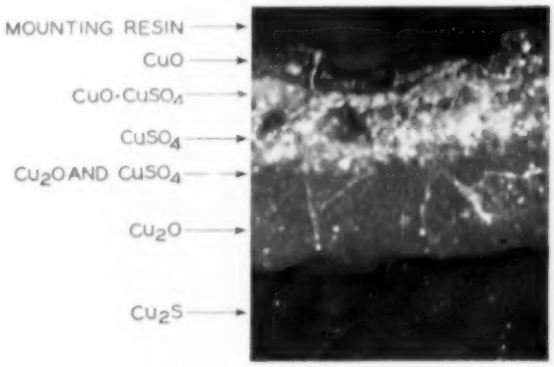

Fig. 1—Color micrograph shows outer oxide and sulfate layers formed during the roasting of Cu_2S. Unetched specimen was photographed under polarized light. X100. Area reduced approximately 10 pct for reproduction.

C. L. McCABE, Associate Member AIME, and J. A. MORGAN are Assistant Professor of Metallurgical Engineering and Junior Research Metallurgical Engineer, Metals Research Laboratory, respectively, Carnegie Institute of Technology, Pittsburgh.

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aime news

Seattle Host To Pacific Northwest Regional Conference

Mining and metallurgical students (standing), were treated to a special dinner at the AIME Pacific Northwest Regional Conference. Seated from left to right: H. Lovenstein, E. R. Marble (General Chairman of the Conference), Charles E. Golson, Roy O'Brien (AIME Field Secretary), K. N. McLeod, David S. Gleason and Dean John P. Spielman.

More than 300 engineers attended the AIME Pacific Northwest Regional Conference at the Olympic Hotel in Seattle. Thirty-five mining engineering students from six western colleges and universities registered.

This *Granddaddy* of AIME regional meetings ran from May 3 to 5th, and included 39 technical papers by experts in the fields of mining, metallurgy, and petroleum engineering. Technical sessions filled the first two days of the meeting, while Sat. was devoted to tours through plants in Seattle, Renton, and Tacoma.

The students came from the University of Nevada in Reno, the Montana School of Mines at Butte, the University of British Columbia at Vancouver, the State College of Washington at Pullman, and the University of Washington in Seattle.

The AIME North Pacific Section, which sponsored the conference, encouraged student attendance by waiving the registration fee, giving reduced hotel room rates, and offering conference luncheon and banquet tickets to students at half-price. A special student dinner Thursday evening was provided by the Colorado Fuel & Iron Corp. and the Harvey Aluminum Co. of U. S. A technical session on minerals industries' education followed the dinner.

Seattle's Mayor Pomeroy extended a cordial welcome at the Metals Branch luncheon, and stressed the need for more college engineering graduates.

J. Gordon Parr, associate professor of metallurgy, University of Alberta, spoke at the luncheon on Thursday. His entertaining and informative talk lived up fully to the promise of its title, *How Does the Metallurgist Get the Urge*?

Desmond F. Kidd, Past-President of CIM, and president and general manager of Attwood Copper Mines, Ltd., spoke at the Mining Branch luncheon on *This Progress of Ours*.

Grover J. Holt, general manager of ore mining for The Cleveland-Cliffs Iron Co., Ishpeming, Michigan, and President-elect of the National AIME addressed the Conference banquet at 7 pm Friday. His topic, *Indian Warpaint in Our Lives Today*, showed the progress in iron mining from the days when iron ore was used only for Indian warpaint, to the present when 87 million tons of ore were mined in the Lake Superior district alone in 1955. This is enough ore to fill a single train 6,600 miles long, originating in Minnesota and extending through Seattle to Tokyo, Japan. In the 100 years since iron ore was first mined in the U. S. three billion tons of ore have been produced which would fill a train long enough to circle around the world nine times at the equator.

This rapid depletion of our known reserves of high-grade ore has forced industry to develop, through research, methods of recovering iron from low-grade taconite ores. Mr. Holt pointed out that as a result of this research, industry has more than replaced the iron ore mined out.

Members of the AIME Bessemer Steel Committee visited the plant at the Lorain Works of U. S. Steel Corp.'s National Tube Division in Ohio on April 25. (See page 741)

An AIME Report:

Long Range Planning For Institute Development

The Background

SINCE its founding 85 years ago the AIME has continued to grow from the original small group of compatible mining engineers to the present complex association of engineers bonded together by their mutual professional interest in exploration, development, extraction, or conditioning processes of the world's great mineral resources. At times this growth process has been slow, but more recently it has increased at an accelerated pace. At the end of 1934 there were 7,163 nonstudent members of the Institute; at the end of 1945 there were 12,910; at the end of 1955 there were 23,723 nonstudent members. The student membership, in stride with the trend, has increased from 579 at the end of 1934 to 2825 at the end of 1955.

Correlative with this growth in numbers has been an inflorescence of mineral technology until today the primary interests of the membership are represented conjointly in the three Branches: Metallurgy, Petroleum, and Mining. The Metallurgy and Mining Branches include Divisions, representing technical specialization, that are in turn composed of committees or groups of increased specialization, until today there are undoubtedly more committeemen in any one of the Divisions than there were in the total membership of the original group that founded the Institute.

As the membership has increased, and as the scientific interests of the members have broadened and deepened, so has the complexity of the administration of the AIME increased. Reorganization has followed organization throughout the history of the administration. Several of the reorganizations have demanded changes in philosophy as to methods of serving the membership more effectively. A typical example of this was a reorganization in 1911 when the first three Local Sections were established. The need for maintaining communications in the Institute as it gained in size as well as the need to overcome the handicap of the distances of groups of members from headquarters undoubtedly compelled what at that time must have been a revolutionary concept to the men who were guiding the destiny of AIME. By 1948 the number of Local Sections had increased to 41, and today we have 70.

More recently, in 1947, the Board of Directors of AIME appointed a committee of M. M. Leighton, Clayton Ball, and H. W. Johnson to study the *Divisionalization and Publication Program* of the Institute. The report of this committee has become known as *The Johnson Report* and was published in the March 1948 issue of MINING AND METALLURGY. Many of the concepts introduced in the report have been incorporated into the fabric of the Institute as we know it today. Although the report was written ten years ago when the total membership was only perhaps 60 pct of that of today, many of the conclusions remain pertinent. Members who are interested in the history and development of the Institute would do well to reread *The Johnson Report*.

Early in 1955, E. H. Robie forecast that the nonstudent membership of the Institute would increase to 27,000 in 1960; 31,000 in 1965; 35,000 in 1970; and to 43,000 in 1980. Again, with increases such as these, the complexity of the problems of administration, especially of the staff functions, will multiply. With this in mind, H. DeWitt Smith, as President of AIME, appointed a committee which he designated as a Long Range Planning Committee to study AIME organization and to recommend means of simplifying the mechanics of operation of the Institute now and in future days of growth. The committee consisted of Andrew Fletcher, 1953 AIME President (Mining) as Chairman; Leo F. Reinartz, 1954 AIME President (Metals); and Carl E. Reistle, Jr., 1956 AIME President (Petroleum).

During the course of the comprehensive study, the committee solicited advice from the members of the AIME Board, the Branch Councils, the Division Chairmen, and other members who had official responsibilities in the activities of the Institute. Thoughtful communications numbered in the hundreds, and uninformed criticism was rare. The advice of Norman Mitchell, member of A. T. Kearney & Co., Chicago, who was a consultant for the Johnson Committee, was also invited.

Previous to the Annual Meeting in New York in February of this year, the committee on Long Range Planning submitted the first draft of its report to the Board of Directors, the three Branch Councils, the Chairmen of the Local Sections, and to the Council of Section Delegates. By broadcasting this draft in advance of the annual meeting, the committee provided, to a large segment of the membership, an opportunity to study and discuss the tentative plan. The report was widely discussed by the various groups at the annual meeting and most of the proposals in the plan were well received. However, the discussion proved that two or three of the proposals needed clarification or modification.

At the final meeting of the 1955 Board, a revised Long Range Planning Report was received by the Board with a vote of thanks to the committee. The Long Range Planning Committee was discharged and the report was passed on to the 1956 Board. At the first meeting of the new Board, President Reistle appointed a committee of the chairmen of the three Branches and the chairman of the Council of Section Delegates to study or work out some of the organizational details and modifications that would be required to implement the plan. This committee was charged to work within the framework of the Long Range Plan; it was cautioned not to come forth with a new Long Range Planning Report. The new committee will report to the Board at the June 1956 meeting.

Although the Long Range Planning Report has had wide circulation among the technical and administrative groups and the Local Sections of the Institute, there is perhaps a segment of the membership that is not affiliated with Local Sections and that has not been able to attend local, regional, or annual meetings. For the benefit of these members, the report is being reproduced here. The membership is invited to study this report and to comment on the proposals.

The Report

The Committee composed of one representative from each of the three Branches was given, in February 1955, the responsibility of developing long range planning for the AIME.

Two memoranda outlining possible solution of certain operating problems, finance, publication, meetings, membership, development, and other related matters, were prepared and submitted to representative members of the Institute to obtain their reaction. A third memorandum was presented to the Board meeting of Nov. 16, 1955.

Based on the very competent letters and meetings with members of the Institute, and supplementing the report, dated Dec. 20, 1955, of Norman Mitchell, member of A. T. Kearney & Co., Chicago, who was appointed by President Smith in November to make an objective study of the Institute and its problems, your Committee makes the recommendation to maintain the general structure of the AIME as it now exists, but with the following changes in structure and organization:

1. Name

a. The name should be *American Institute of Mining, Metallurgical, and Petroleum Engineers.*

b. The abbreviation of *AIME* should be retained.

c. The symbol should be redesigned by including in the background a drilling derrick or some other item that is representative of the petroleum members.

2. Branches

a. The subdivision of the membership groups should no longer be known as Branches but as Societies, and under the following titles:
Mining Engineering Society of the AIME
Metallurgical Engineering Society of the AIME
Petroleum Engineering Society of the AIME

b. Each society should form its own committee on education and on economics, in accordance with its own need. These committees would then be coordinated by an AIME council, or professional division, that would have a representative on the AIME Board of Directors. This Council would cover all three Societies in the Institute, and all AIME members could participate in it, as well as belong to their own Society.

c. Subject to the approval of the AIME Board, each Society should organize its own Executive Committee, with officers and bylaws.

3. Directors

a. The number of AIME Directors should be reduced to 21, and the honor and responsibility of office be increased.

b. The President, President-Elect, and Past-President should serve as Directors. Each society should have its own Nominating Committee for the election of its Directors, and six additional Directors from each Society should serve as Board members. In the first year of reorganization, two Directors would be elected for three years, two for two years, and two for one year; thereafter, two would be elected each year by each Society for three-year terms.

c. Transportation, but not food or housing expense, of any Director to the four quarterly Board meetings, should be paid by the AIME.

d. The duties of the Board should be to establish the broad policies of the AIME, to maintain and protect the integrity and professional standing of the members, to plan and be responsible for the Annual Meeting, to handle the joint finances of the various groups, and to review and approve the recommendations of the President for membership on the standing committees. The Board should also have the power to approve or disapprove any changes in the organizational setup or financial policies of the individual Societies.

4. President

a. Each society should name the President every third year. The Nominating Committee of the individual society from whom the President is to be elected should make the nomination for that particular year.

b. The President's transportation, but not food or housing expense, should be paid by the AIME with an upset limit to be determined annually by the Board.

5. Sections

a. As sections over the coming years will be influenced more by professional than by geographical lines, each Society should be given authorization to set up its own geographical areas and organize sections to meet its requirements. Until changed by the Board, the minimum requirement for the setting up of any section should continue to be 25 members.

b. Local sections can and should be flexible in their organization and operation. Some may be organized on a geographical basis, and some on a professional basis. It was not the intent of the Long Range Planning Committee to force a reorganization of local sections, but to let each section have the freedom to organize according to the needs and wishes of its membership. The Council of Section Delegates may be continued as an all-Institute organization, with its functions changed somewhat and some organization of section delegates on a society basis.

6. The Council of Section Delegates

a. As the Council has many desirable features, the Committee recommends that each society should set up its own Council of Section Delegates, whose primary responsibility should be to keep the Directors of that particular society informed. If, however, a society does not desire to have its own Council of Section Delegates, it will be under no obligation to do so. The society should pay the expenses of its own Council.

7. Initiation Fees and Dues

a. The Committee recommends that for the next three-year period initiation fees should be reduced from $20 to $10, and the respective Society be refunded the $10.

b. The Committee believes that the dues for all three societies should be the same, and that for the time being at least, the $20 fee should be retained.

c. The Committee recommends that the refund of 50 cents a member should be continued, but that for the next three years, while the suggested reorganization is taking place, the refund should not be any greater.

d. The AIME Board should have the right to reduce or increase the initiation fees, dues, or rebates any time upon a majority vote of the Board members.

8. Finances

a. Each society should have full responsibility for operating at a profit, as shown by the AIME books. After expenses have been met, each society should have authority to spend all surplus funds after 25 percent of such surplus funds have been set aside for the interests of the AIME as a whole.

9. By-laws

a. The AIME By-laws should be rewritten and simplified.

10. Meetings

a. The Committee recommends to the Board that a decided change should be made in the Annual Meeting program. For example, the number of technical sessions should be reduced, one or more joint sessions of the three societies be organized, and luncheon meetings be addressed by outstanding speakers on timely subjects of a general nature.

b. All business should be divorced from the Annual Banquet and only top awards should be given at that time. The other awards should be given at society or regional dinners or meetings, which it is believed will be strengthened by the transfer to them of some of the technical sessions.

c. The President should make his report on *State of The Institute* at an afternoon session during the Annual Meeting.

11. Conclusion

It is hoped that the above suggestions and comments will result in each Society having as much autonomy as possible, and that the AIME will grow into a single and stronger Institute in which the best interests of all members are furthered.

COMMITTEE FOR AIME LONG RANGE PLANNING
Leo F. Reinartz—Metals
Carl E. Reistle, Jr.—Petroleum
Andrew Fletcher, Chairman—Mining

Blast Furnace NOHC Conference Held in Cincinnati

The thirty-ninth conference of the AIME Blast Furnace, Coke Oven, and Raw Materials Committee and National Open Hearth Steel Committee was held at the Netherland Plaza Hotel, Cincinnati, April 9-11 of this year. Attendance records were broken by both committees with 1105 registering for the open hearth conference and 459 signing up for the blast furnace meetings.

Sessions on problems of raw material supply and quality, held Monday morning, drew close attention, particularly the sessions on sintering. Refractories papers presented in the afternoon by the open hearth committee, created so much interest that the audience overflowed into the hall. Other sessions covered blast furnace operations, desulfurization, coal and coke, basic and acid operations, cold metal and foundry practice, and combustion.

The luncheon and business meeting of the blast furnace committee on Tuesday, was well attended and the annual fellowship dinner that night filled not only the floor, but the balcony of the hotel's Hall of Mirrors.

At the annual fellowship dinner, the conference presented the JOURNAL OF METALS Award to three men from the University of Minnesota for their contribution to industry knowledge of the sintering process. The recipients of the award were: T. L. Joseph, professor of metallurgy; Gust Bitsianes, associate professor of metallurgy; and R. D. Burlingame, Weirton Fellow. Their work was made possible by the fellowship program of the National Steel Corp. The title of the winners' paper was *Reaction Zones in the Iron Ore Sintering Process.*

Guest speaker at the dinner was Thomas R. Reid, director of civic affairs, Ford Motor Co. A member of the Hoover Commission's committee on business organization, Mr. Reid is also chairman of the subcommittee on special problems; both committees are in the Dept. of Defense. Discussing the recommendations of the Hoover Commission Report which have been acted upon, Mr. Reid urged the adoption of the remaining proposals, stressing the advantages which would accrue. The speaker was formerly vice president in charge of human relations, McCormick & Co., and held the chairmanship of the Surplus Manpower Commission.

Wednesday morning nine buses took approximately 400 registrants out to the Armco Steel Corp.'s enlarged plant at Middletown. Visitors toured the newly opened coke operation, visited the blast furnace and toured the No. 2 open hearth shop. Luncheon was served at the Hotel Manchester at Middletown through the compliments of Armco.

Attendance Exceeded 1500

The record registration overflowed to the Hall of Mirrors Balcony at the Netherland Plaza Hotel for the Fellowship Dinner.

Nine Buses For Plant Trip

Over 400 visited the blast furnace at Armco Steel Co.'s enlarged plant in Middletown.

Sept. 15, 1956 is the deadline for Institute of Metals Div. papers (4 copies) for the 1957 New Orleans Annual Meeting and the deadline for all Iron & Steel Div. and Extractive Metallurgy Div. papers (3 copies) that are to be considered for preprinting. Papers received by this deadline but requiring revision may not be processed in time to permit scheduling for this meeting.

Seated at the head table enjoying the Fellowship Dinner are, left to right: J. W. Duncan, E. A. Kercsmar, R. E. Powers, John Chipman, A. W. Thornton, Grover Holt (AIME President-Elect), C. T. Marshall, L. F. Reinartz, D. R. Mathews, F. M. Hamilton, W. E. Conway, F. M. Stephens, and R. W. Shearman.

Chatting between sessions, left to right: Harold P. Gaw, John Marsh, and Thomas R. Reid.

In animated discussion, left to right: Grover Holt, T. L. Joseph, and L. F. Reinartz.

LEFT: Toastmaster John Marsh, left, provides an interested audience for John Chipman, ISD chairman, before offering his own ideas on the subject under scrutiny. Mr. Marsh was the 1955 Howe Memorial Lecturer. RIGHT: William E. Marshall, Blast Furnace, Coke Oven & Raw Materials Committee Chairman, makes a salient point.

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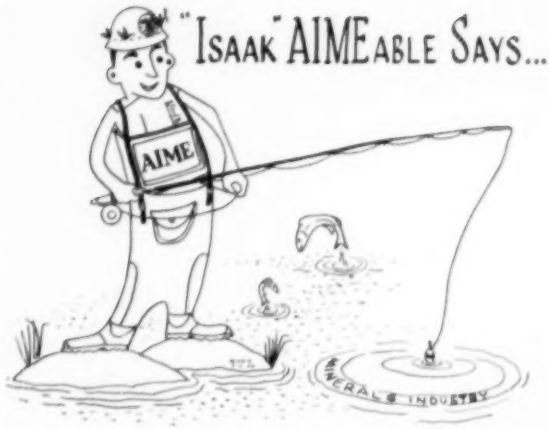


KEEP FISHING FOR GOOD MEMBERS THERE IN THE POOL

The days of the fishing stories have come around once more. Usually these stories are not about those that were caught, but about the *whopper* that got away.

Ole Isaak AIMEable, in those lucid moments when the fishing fever is not upon him, although he brags about those he nailed, and how the *beastie* fought to get away, gives some thought to those *beauties* at the bottom of a pool, or under some rock in the stream, who do not even rise to his lure.

If you ask a successful fisherman the reason why he brings back a creel full, while his next door neighbor usually comes home empty-handed, he will tell you it is a question of patience. Patience to learn the lore of the sport, and patience in fighting the fish, till you bag him.

It is a funny thing but this same quality of patience and pertinacity, is one that we need in signing up new members for the Institute. We need patience in locating the big ones; patience in a cautious approach, so as not to scare him away; patience in answering his objections and overcoming his resistance; patience once we have him on the hook, to get his application blank filled out and signed; then we finally have him.

We have not surveyed the membership of AIME to find out just what proportion are devotees of the sport of fishing, but my guess is that it will be quite high, so here's an appeal to you *Waltons* of this day! Why not imitate ISAAK AIMEable and fish for new members?—*C. E. Golson.**

AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC.

29 WEST 39TH STREET NEW YORK 18, N. Y.

New England Regional Conference

Scores With Plant Tours, Technical Sessions, Dinner

The Tenth Annual New England Regional Conference was held at the Waverly Inn, Cheshire, Connecticut, on April 20 and 21. The conference, which included two days of technical meetings, a fellowship dinner, and a choice of plant trips, was attended by 190 registrants.

Technical sessions were held on Friday and Saturday mornings. The metal science session on Friday scheduled talks on: *Fundamentals of Deformation in Metals* by Bruce Chalmers, Harvard University; *Deformation of Polycrystalline Metal* by W. R. Hibbard, Jr., General Electric Co.; and *Characteristics of Wrought Metals* by J. Lester Klein, Nuclear Metals Corp. W. A. Backofen, of MIT was chairman.

The Saturday morning session on metal engineering featured talks by Paul Loewenstein, Nuclear Metals Corp., on *Lubrication and Hot Working of Reactive Metals;* Samuel Storcheim, Atomic Energy Div., Glenn L. Martin Co., on *Metal Powder Rolling—Past, Recent, New Developments;* and Michael Sendzimir, Armzen Co., who discussed *Latest Developments on the Sendzimir Cold Strip Mill.* Sidney Siegel, General Plate Div., Metals & Controls Corp. presided as chairman.

Highlights of the Friday afternoon program were plant trips, for which 130 turned out, to Scovill Mfg. Co. in Waterbury, Conn. and to Landers, Frary & Clark in New Britain, Conn. At Scovill the group saw continuous casting of brass and operation of the strip mill. Scovill has the largest rolling mill built for the brass industry. At Landers, the conveyor technique for the assembly of percolators was of particular interest because of its application to automation.

Benjamin Franklin and his role in making America a leader in science was the subject of the after-dinner speaker, Leonard W. Labaree, history professor, Yale University, who chose to discuss *Franklin and His Scientific Friends,* at the Fellowship Dinner. Professor Labaree pointed out that in Franklin's time there were no scientific journals, and personal letters were used as the medium for communicating theories and research results to other workers in the field. It was through correspondence of this type that Franklin became renowned for his experiments on static electricity. Later, Franklin was instrumental in organizing the first scientific society in America—the American Philosophical Society. It was in Great Britain and Europe, particularly in France, that Ben Franklin received his greatest recognition as America's outstanding natural philosopher.

Following a Dutch treat luncheon on Saturday noon, a business meeting of the New England Regional Conference Committee was held. The election of officers for next year included: W. A. Backofen, chairman; D. E. Trout, vice chairman; D. L. Martin, secretary; Sidney Siegel, treasurer; K. H. Mairs, past-chairman; and members at large: J. Chafey, J. J. Burke, P. J. Clemm.

Much credit for the successful meeting is due to K. H. Mairs, W. A. Backofen, G. W. Coleman, D. E. Trout, and their very active conference committee.

Guests at the fellowship dinner heard an entertaining talk by Leonard Labaree, seated right; flanked at left by toastmaster J. L. Christie. Standing left to right: K. H. Mairs, section chairman; G. W. Coleman, treasurer; D. E. Trout, secretary.

A large group turned out to visit Scovill plant in Waterbury, Conn. where they saw continuous casting of brass and the largest rolling mill built for the brass industry.

Around the Sections

C. W. Conn, retiring Chairman and organizer of the Detroit Section, NOHC, holding the stainless steel gavel presented to him at a recent Section meeting. With Mr. Conn are M. J. Smith, W. J. Scharfenaker, and H. W. Clark, all of the Detroit Section.

• More than 130 attended the dinner-meeting of the **Detroit Section, NOHC,** on April 25 at the Horace Rackham Memorial Institute. The speaker was James J. Bowden of Bowflux Co., Cortland, Ohio, whose subject was "Melting Practice and Its Effect on Finished Steel."

Paul Lindberg, McClouth Steel Corp., Trenton, Mich., was elected Chairman Detroit NOHC. Other officers are: Martin Groat, Vice Chairman; John C. Brown, Treasurer; R. Lautzenhiser, W. J. Scharfenaker, F. Stroup, M. J. Smith, H. F. Lesso, K. Lewis, L. Cummings, H. Moyer, and J. Yoxall, Directors.

After the elections Mr. Lindberg assumed office and presented C. W. Conn, outgoing Chairman and organizer of the Section, with a stainless steel gavel. The gavel was engraved as follows: "N.O.H.C. Detroit Section. Presented to C. W. Conn, First Chairman, April 25, 1956."

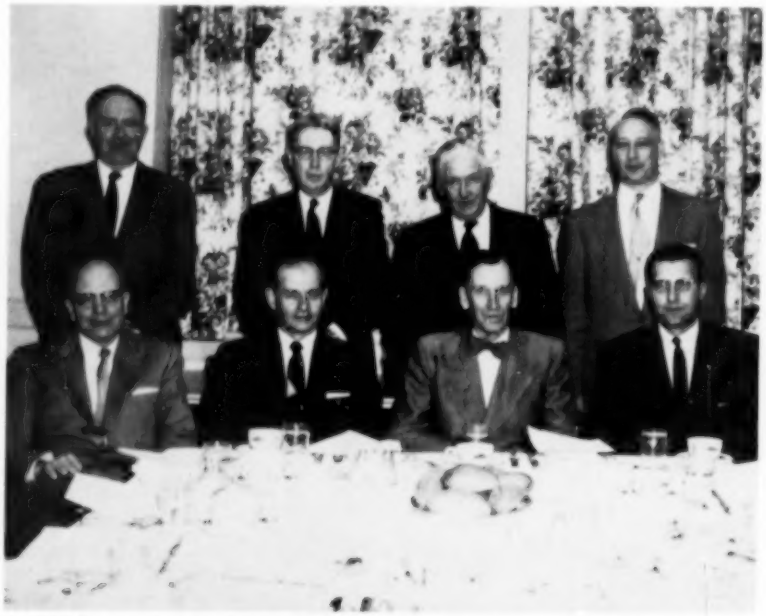
• The **El Paso Metals Section** and the Kidd Mining Club met on April 19 at Seamon Hall, Texas Western College. After a bean feed senior students presented papers on their research problems.

• The **Washington, D. C., Section** held a dinner-meeting on May 8 at the Cosmos Club. The principal speaker was Simon D. Strauss, vice president, American Smelting & Refining Corp.

• Ward Minkler, assistant manager for market development, Titanium Metals Corp. of America, addressed the **New York Section** on March 29. Mr. Minkler discussed the problems of the titanium industry today, and titanium's future. This was a dinner-meeting at the Mining Club held jointly with the Section's Physical Metallurgy Group.

AIME President Tours Western Local Sections

Mr. Reistle made a tour of some of the Local Sections in April. His first stop was at Salt Lake City, where he was the guest of honor at the annual spring dinner-dance of the Utah Section. Mr. Reistle then went on to Butte and attended a luncheon and a banquet given for him by the Montana Section at which he was the principal speaker. He also spoke at a convocation of students and faculty at the Montana School of Mines. The next day Mr. Reistle left for Spokane and attended a meeting of the Columbia Section. On April 11 he was the guest of honor at a dinner party held by the Coeur d'Alene Subsection at the Union Legion Hall, Kellogg, Idaho. Mr. Reistle also visited the San Francisco, Nevada, and Chicago Sections. He was accompanied on his tour by Mrs. Reistle, Mr. Kirkendall, and Mr. O'Brien.



This photograph was taken at the luncheon held on the occasion of the visit by Carl E. Reistle, Jr., AIME President, to Butte. Left to right: Seated—J. R. Van Pelt, president, Montana School of Mines, and Montana Section Chairman; Mr. Reistle; F. W. Strandberg, chief engineer, The Anaconda Co.; and C. J. Hicks, Montana Section Secretary. Standing—E. I. Renouard, Jr., manager of mines, The Anaconda Co.; Roy E. O'Brien, AIME Field Secretary; E. P. Shea, head, Geological Dept., The Anaconda Co.; and Ernest Kirkendall, AIME Secretary.

Personals

T. D. JONES

T. D. Jones, chief lead refinery metallurgist, American Smelting & Refining Co., was one of six prominent graduates of the College of Engineering, University of Wisconsin, awarded a citation for distinguished engineering services on Engineers' Day, May 4. Mr. Jones received a B.S. in metallurgy from the university in 1922, and the professional degree of metallurgical engineer in 1929. He was chairman of the Extractive Metallurgy Div. of the AIME in 1952, and is a member of the Institute Admissions Committee, National Steering Committee, and the EMD Executive Committee.

George A. Alers, former research engineer for Westinghouse Research Laboratories, Pittsburgh, Pa., is now a member of the engineering staff, physics department of Ford Motor Co., Dearborn.

W. B. F. Mackay has left the University of Minnesota in Minneapolis where he taught in the department of metallurgy, to join Atlas Steels Ltd., Ontario, Canada.

Edgar C. Bain has been honored by U. S. Steel Co. of which he is vice president of research and technology. A building in their new research center in Monroeville, Pa., is named the Edgar C. Bain Laboratory of Fundamental Research. Dr. Bain achieved international recognition principally for his work in the field of alloy steels. In 1952 the leading French society of metallurgy bestowed its grand medal on him, the first American to be so honored. He is also the recipient of awards from Franklin Institute and the ASM. In 1952 Dr. Bain delivered the Schwab Memorial Lecture at the AISI annual meeting. A native of Marion, Ohio, he graduated from Ohio State University and has been associated with U. S. Steel since 1928.

Joseph J. Chase is chief engineer, TurboTronics Div., Summit-Roberts Products Inc., Cleveland. He was formerly with JeTool Inc., Euclid, Ohio.

Robert B. Corbett is now assistant to the president, Heppenstall Co., Pittsburgh. Dr. Corbett has been director of research at the company since 1952, and will continue to head this department. A graduate of Carnegie Institute of Technology, he received his Doctorate from the University of Pittsburgh.

Milton H. Koeneman has resigned from his post as sales engineer for Laclede Arch Co. in St. Louis to join the staff of John Mohr & Sons in Chicago.

R. L. Rickett, who was associated with the Fundamental Research Laboratory, U. S. Steel Corp. in Kearny, N. J., has moved to the company's Edgar C. Bain Laboratory Research Center in Monroeville, Pa.

Louis Horvath is now research engineer, North American Aviation Inc., Downey, Calif. Mr. Horvath was formerly assistant research engineer for Bridgeport Brass Co., Bridgeport, Conn.

Bennett V. Whiteson has left M. H. Harper Co., Morton Grove, Ill., to join Douglas Aircraft Co., Santa Monica, Calif. where he will be a materials and process engineer.

Nathan M. Levine has been named supervisor of extractive metallurgy and mineral dressing in the metals research department of Armour Research Foundation, Illinois Institute of Technology, Chicago. A specialist in hydro-metallurgy, Dr. Levine will be in charge of research activities in concentration of ores and extraction of metals. He is a native of New York City and received a B.S. degree in mathematics from City College, N. Y. in 1939, and a B.S. in mineral dressing engineering from Columbia University where he also obtained his Doctorate. Dr. Levine was head of the leaching section of the minerals beneficiation laboratory at Columbia and also did research work at the University of Wisconsin. From 1945-47, he was mill metallurgist for U. S. Smelting & Refining Co. at Bayard, N. M. He is a member of AIME, Sigma Xi and Phi Beta Kappa.

James H. Mohr is chief metallurgist, Whitney Chain Co., Hartford, Conn. He was formerly with Remington Arms Co., in Bridgeport, Conn.

Mervin S. Allshouse, formerly laboratory metallurgical engineer at Amplex Mfg. Co., Detroit, has joined the atomic power division of Westinghouse Electric Corp., Pittsburgh.

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The Norelco Basic X-ray Diffraction unit is the fundamental tool for structural analysis utilizing film measurement techniques. Furthermore, it is the basic foundation upon which all other associated instrumentation is built to provide facilities for X-ray Diffractometry or X-ray Spectrography.

When X-rays arising in properly designed apparatus are directed into a sample material, a series of secondary beams of radiation are reflected from the specimen upon a properly sensitized film—a series of concentric lines appear on the film. These lines are the result of reflections from the atomic planes of the specimen and since no two materials will present the same film pattern—the method can be used for positive identification. Identification, or detection of changes, or impurities in even minute specimens are based upon reflected radiation arising from the irradiated specimen and a sub-sequent pattern which it produces on a film.

Various precision-built X-ray cameras are available such as Powder Cameras, Precision Back-Reflection Camera, Micro Camera, Flat Plate Camera, Single Crystal Cylindrical Camera and specialty cameras. These cameras differ in function and their recommended use is dependent upon the types of specimens to be examined, as well as the information required.

Adoption by industry of X-ray diffraction for research and processing control techniques has helped industries by speeding the classification and identification of essential materials and has also played a major role in the development of many newly introduced industrial materials.

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Anaconda Announces Promotions

CLYDE E. WEED

Clyde E. Weed was elected president of The Anaconda Co., succeeding **Robert E. Dwyer,** who retires July 1, 1956, after 53 years of service with the company. **Elbert O. Sowerwine** former vice president of the company, retired on June 1 of this year. Formerly vice president in charge of operations, Mr. Weed will also head three subsidiary companies: Chile Copper Co., Chile Exploration Co. and Andes Copper Mining Co.

THOMAS A. CAMPBELL

Other promotions announced by Anaconda are: **Thomas A. Campbell,** former executive vice president of the Chile Exploration and Andes Copper Companies, to vice president of the parent company and president of Anaconda Sales Co., and **Charles Brinckerhoff** from general manager in charge of S. American operations of the two subsidiaries, to vice president of both companies. **W. Kenneth Daly** has been elected to vice president and comptroller of Anaconda.

The first engineer to head the company since 1915, Mr. Weed was born in Mooreshead, Mich., and received a mining engineering degree from Michigan College of Mines and Technology in 1911. One of his early jobs was with Inspiration Consolidated Copper Co., an affiliate of Anaconda in Miami, Ariz. In 1938 he joined Anaconda as general manager of mines and became vice president in 1942. Mr. Weed played a prominent role in the planning and development of the Greater Butte Project. In 1951 AIME awarded him their William Lawrence Saunders Medal.

After graduating from Yale in 1919, Mr. Campbell began his career as a metallurgist for Remington Arms Co. in Bridgeport, Conn., and by 1936 was assistant general manager of Chile Exploration Co. He is a member of AIME, Mining and Metallurgical Society of America, and Yale Engineering Society.

W. KENNETH DALY

Mr. Brinckerhoff, a native of Minneapolis, received his degree in metallurgical engineering from the Columbia University School of Mining. He has been with Anaconda's subsidiaries since 1926. Mr. Daly who was born on Staten Island, N. Y. joined Anaconda in 1917. He has also been vice president of Basic Magnesium Inc.

CHARLES BRINCKERHOFF

S. E. MADDIGAN

S. E. Maddigan, assistant director of Kaiser Aluminum's dept. of metallurgical research, has been transferred from the Spokane laboratories to the Oakland, Calif. headquarters, where he will act as a special assistant to Paul P. Zeigler, director of the department of metallurgical research. Before joining Kaiser Aluminum, Dr. Maddigan served successively as head of the physics and electrochemical research laboratory for Chase Brass & Copper Co. and as director of the British Columbia Research Council.

Gilbert A. Lenning is now associated with Titanium Metals Corp., Henderson, Nev. He was formerly principal metallurgist at Battelle Memorial Institute, Columbus, Ohio.

Francis A. Muth is general superintendent, American Smelting & Refining Co., Baltimore.

Douglas C. Haag is associated with Titanium Metals Corp. of America, in their process control department, located in Henderson, Nev.

S. W. Madsen, vice president of the Shieldalloy Div., Metallurg Inc., New York, has relocated to the company's plant in Newfield, N. J.

George W. Coleman, formerly general manager, Snell Mfg. Co., Fiskdale, Mass., is now with the Parker Mfg. Co., Worcester, Mass.

Peter J. Zorena is now a metallurgist for Inland Steel Co., East Chicago, Ind. Prior to accepting this post, Mr. Zorena was research assistant, metals research laboratory, Carnegie Institute of Technology, Pittsburgh.

Robert E. Thomas is product metallurgist, American Steel & Wire Div., U. S. Steel Corp., Waukesan, Ill.

M. Merlub-Sobel is staff chemical engineer, Curtis Wright Corp., Clifton, N. J.

John D. Wood has joined Kaiser Aluminum & Chemical Corp., Halethorpe, Md., as a metallurgist.

Edwin F. Mitchell is sales manager, Alloy Castings, Blau-Knox Co., East Chicago, Ind. He formerly worked for Continental Foundry & Machine Co., Chicago.

Ford W. Knight is metallurgist, raw materials technology section, E. I. du Pont de Nemours & Co. Inc., Savannah River Plant, AEC, Aiken, S. C. Mr. Knight was with The Anaconda Co., Anaconda, Mont.

Martin J. Hughes is mine manager, iron ore mining operations, Kaiser Steel Corp., Eagle Mt., Riverside County, Calif. Mr. Hughes was superintendent of iron ore mining and beneficiation at the Lone Star Co. in Texas, and had been with that company for seven years. Prior to that, he was engaged in mining operations in Chile and also supervised mining operations in Cuba, and for U. S. Gypsum Co. in Texas. Mr. Hughes succeeds **James G. Hansen** who will now supervise the opening of the Cushenbury limestone deposits, Lucerne Valley, for Permanente Cement Co., which is managed by Kaiser Steel.

Paul E. Crow, formerly superintendent at Phillips Foundry, Bakersfield, Calif., has joined Barker Food Supply Co., in Los Angeles.

John E. Seward, former blast furnace superintendent, South Chicago Works, Youngstown Sheet & Tube Co., Chicago, has joined Jones & Laughlin Steel Co., Pittsburgh. Mr. Seward will be assistant to the open hearth superintendent at the Pittsburgh Works, Pa.

Donald B. Hoiekvam is vice president and manager of operations for the Montana Mining & Milling Co., Helena, Montana. Previously he was general foreman American Metallic Chemicals Corp., Portland, Ore.

John N. Andersen has joined Kennecott Titanium Development Corp., Columbus, Ohio. He was formerly associated with Stauffer Chemical Co., Niagara Falls, N. Y.

Aaron Wachter, head of the corrosion department, Shell Development Co., in Emeryville, Calif. was presented with the 1955 Outstanding Service Award of the Western Region, NACE. Dr. Wachter, immediate past-president of NACE, received the award at the Fifth Annual Corrosion Conference Banquet in San Francisco.

E. P. Scala, formerly process metallurgist for Chase Brass & Copper Co. in Waterbury, Conn., has accepted the post of chief of materials section, advanced development division, Arco Mfg. Co., Stratford, Conn.

Robert H. Read is in the metals research department Armour Research Foundation, Chicago.

*EDP

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Adding the Diffractometer to the Basic Diffraction Unit at any time, provides a means by which interpretations are speeded and facilities are provided for equal or greater analysis. Interpretations can be positive and more accurately presented. A choice of any sensitive radiation detector tube, in place of the film, receives the reflections from the specimen. Subsequent electronic integration and amplification of these impulses serve as a means of developing peaks and valleys on a chart — corresponding to the diffraction lines on the film pattern. This newer method is extremely rapid, provides better accuracies and guarantees unequalled reproducability—with greater ease than other methods of analysis. Specimens may be compared quantitatively and qualitatively.

The Norelco Diffractometer includes the Basic X-ray Diffraction Unit except that several detection counters and electronic circuitry are used in place of or used as a supplement to cameras. The basic unit is always available as a four-window radiation source for the simultaneous operation of cameras and goniometers.

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The X-ray tube produces characteristic excitation of the specimen whose wavelengths are made to fall upon an analyzing crystal. Heterogeneous wavelengths are then separated by the crystal into components, each of which is singularly distinguishable. The apparatus provides qualitative as well as quantitative data on the relative presentation of elements present in a compound. Accurate determinations can be made from trace amounts to 100% of a given element — in a matter of minutes without necessity of film or plate standardization or processing techniques. The equipment is easily operated by laboratory personnel.

Specimens of any nature may be accommodated. Latest development in helium atmosphere chambers and in flow detectors, now extend routine analytical utilities to include reproducable, accurate and simplified evaluations for elements down through magnesium (Atomic #12).

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C. Sheldon Roberts is now associated with Shockley Semiconductor Laboratory in San Antonio, Calif. Prior to this, Mr. Roberts was a research metallurgist at Dow Chemical Co. in Midland, Mich.

James J. Bean is chief metallurgist, Miami Copper Co., Miami, Ariz.

R. T. Whitzel has been named general production manager, Aluminum Co. of America. Since 1952, Mr. Whitzel has been general manager of the smelting division. In his new position, he will be responsible for all metal production and fabricating operations of the company. After graduation from Ohio State University, with a Master's degree, Mr. Whitzel joined Alcoa in 1915 as a metallurgical engineer at the Niagara, N. Y. works. He became assistant manager two years later, and by 1945 he was head of all Massena operations.

GEORGE H. THURSTON

George H. Thurston will represent Duraloy Co., Scottdale, Pa., in sales and service for all of California north of Los Angeles. Mr. Thurston, who specialized in metallurgy at the University of California and Case Institute of Technology, has been a consulting metallurgist. His articles have appeared in publications on the Pacific Coast.

F. R. Morral has joined Batelle Memorial Institute, Columbus, Ohio, as Div. Consultant. Dr. Morral was formerly head of the X-ray Laboratory, division of metallurgical research, at Kaiser Aluminum & Chemical Corp., Spokane.

Roger R. Turk is a metallurgical engineer for North American Aviation Inc., Downey, Calif. He was supervisor of the metallurgical laboratory, Tungsten & Chemical Div., Sylvania Electric Products, Montebello, Calif.

Richard Summers, formerly general manager, Cupa Mfg. Corp., Bridgeport, Conn., has accepted a post with Bridgeport Testing Laboratory Inc.

LYLE HALLBERG

Lyle Hallberg is mineral testing engineer, Western Machinery Co., San Francisco. Mr. Hallberg was junior metallurgist, American Smelting & Refining Co., Colville, Wash., and has been active in mining operations in Idaho and Montana. He graduated from the Montana School of Mines in 1950 with a B.S. degree in metallurgical engineering.

William P. Roe is now associated with Southern Research Institute, Birmingham. Previously, Mr. Roe worked as a research metallurgist in the Titanium Div., National Lead Co., South Amboy, N. J.

M. C. Irani has been appointed vice president of research and development of the metals chloride division, Salem-Brosius Inc., Pittsburgh. Mr. Irani had been a member of the research foundation, Colorado School of Mines. Prior to accepting his new post, he had been associated with Julius Hyman & Co., Denver, and Booth Engineers, Salt Lake City. In his new capacity, Mr. Irani will deal with the development of applications for the division's new high temperature chlorinating furnaces. His published works include: *Thorium as a Source of Atomic Power*. Mr. Irani is a member of the American Chemical Society and AIME.

M. C. IRANI

Edward R. Borcherdt has been promoted to director of mining research with headquarters in Butte, and **Francis L. Holderreed** to director of metallurgical research for The Anaconda Co. in Anaconda, both in Montana. Mr. Borcherdt, a native of Iowa, has been chief research engineer for the company since 1938. A graduate of the University of Michigan, he received his degree in mining engineering from Michigan College of Mines. Mr. Borcherdt began as an assistant geologist at Anaconda in 1920, and organized the engineering research department in 1926. Mr. Holderreed, who hails from Oklahoma, has been with the company since 1940, at which time he was a chemist, joining the research department the following year. He received an M.S. degree in metallurgy from the Montana School of Mines after graduate work at the University of Oregon.

Michael F. Demshar is superintendent, Blooming Mill, Wisconsin Steel Div., International Harvester Co., Chicago. Prior to this, he was superintendent, Rolling Mills, Wisconsin Steel Works, Chicago.

Carl S. Wiedman is now with the Walmet Corp., Madison Hts. Mich. He was formerly associated with General Electric Co.'s carbology department in Detroit.

Edward W. Bullard, San Francisco Advisory Committee, Engineering Societies Personnel Service Inc., has resigned. Mr. Bullard, president of the E. D. Bullard Co., represented his section for the committee for 18 years, the last seven years as chairman. He was presented with a certificate for outstanding service to the engineering profession from the ESPS National Board of Directors. **Herbert A. Sawin**, assistant sales director, Yuba Mfg. Co., has accepted appointment by James P. Bradley, chairman of the San Francisco Advisory Committee for the ESPS. Mr. Sawin and other representatives from other sections of national engineering societies will counsel, guide, and review ESPS operations to assure satisfactory employment service to engineers.

R. J. McCrary joined the Volcan Mines Co. as metallurgist, in Ticlio, Peru. He was formerly assistant general superintendent and metallurgist for the U. S. Tin Corp. of Lost River, Alaska.

Edward Day Dickerman, metallurgist and field engineer, Minerals Engineering Co., Grand Junction, Colo., is now metallurgist with Galigher Co., Monticello, Utah.

Jack M. Law has resigned from his post with Sylvania Electric Products Inc., Seneca Falls, N. Y., to become a metallurgist for the Power Equipment Co. in Galion, Ohio.

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X-ray Diffractometers

X-ray Spectrographs

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Magnetism Conference In Boston Oct. 16-18

A conference on magnetism and magnetic materials is scheduled for Oct. 16, 17, and 18, 1956, at the Hotel Statler, Boston. Sponsored by the magnetics subcommittee of the AIEE basic science committee, the conference will bring together those interested in basic and applied work on magnetism. Cooperating with AIEE, are the American Physical Society, the IRE and AIME.

Tentative plans are to include sessions on apparatus and magnetic design, losses in soft magnetic materials, high frequency phenomena, magnetic anisotrophy, and magnetism and physical metallurgy. Programs, containing abstracts of papers, will be distributed before meetings.

It probably will not be possible to include in the program all of the papers submitted, because of time limitations and the desirability of avoiding simultaneous sessions. Final selection of papers will be made by the program committee composed of: C. P. Bean, R. M. Bozorth, H. Brooks, D. R. Brown, J. E. Goldman, W. R. Hibbard, Jr., J. A. Osborn, and G. T. Rado. Presentations will vary from 10 to 30 minutes. Titles must be submitted by June 15 and abstracts of 200 to 500 words by August 1. The complete papers are to be handed in at the conference, for publication in *Conference Proceedings*.

Prospective Authors should submit titles no later than June 15, writing to the Program Committee Chairman: C. P. Bean, General Electric Research Laboratory, The Knolls, Schenectady, N. Y. Prospective Exhibitors should contact the Manager of Exhibits, R. Rimbach, Richard Rimbach Associates, Inc., 845 Ridge Ave., Pittsburgh 12. For further information write the Local Conference Committee Chairman, T. O. Paine, Measurements Laboratory, General Electric Co., West Lynn, Mass.

Members May Recommend AIME Awards Candidates

Funds are sufficient to finance all of the usual AIME Awards to be presented at the Annual Meeting in New Orleans February 24 to 28, 1957, except the Ramsay Medal for achievement in coal mining.

Award committees have been named, and the chairmen will be glad to hear from any AIME members who wish to suggest the name of a candidate worthy for consideration by the appropriate committee. Their names follow: W. A. Dean, committee chairman, James Douglas Medal for distinguished achievement in nonferrous metallurgy; C. E. Weed, chairman, W. L. Saunders

(Continued on page 815)

Obituaries

Allan R. Volmar (Member 1952) died in an automobile accident near Stow, Ohio, last July while on his way to Akron for a day of training at the Naval Air Reserve Station. Born in Pittsburgh in 1930, Mr. Volmar received his B.S. in metallurgy at Case Institute of Technology in 1952. He began his promising career at Reliance Electric & Engineering Co., Cleveland, as a cadet engineer that same year. In March 1953 he became project man for the nonferrous foundry. By July 1953 he was methods engineer, and in May 1954 was promoted to foreman. Active in sports, Mr. Volmar taught swimming during his high school days, played football at Case, and was a member of the championship softball team at Reliance Co.

Alfred D. Beeken (Member 1950) died suddenly on March 26, 1956. He was metallurgist and general sales manager for Vulcan Crucible Steel Co., Alquippa, Pa. where he had worked since 1914. Mr. Beeken was born in Fanwood, N. J. on Jan. 13, 1891, and studied at Carnegie Institute of Technology, receiving his B.S. degree in metallurgical engineering. His affiliations included membership in AISI and AIME. Mr. Beeken was also a member of the Metals Handbook Committee and chairman of the tool steel subcommittee, both of ASM.

Necrology

Date Elected	Name	Date of Death
1950	Alfred Beeken	Mar. 26, 1956
1920	Charles L. Bradbury	Apr. 3, 1956
1899	Norman Carmichael	Nov. 15, 1955
1917	Martin Fishback	Unknown
1932	Victor Garate Valdez	Apr. 18, 1956
1908	Henry S. Geismer	Aug. 20, 1955
1949	Joseph C. Long	Apr. 1, 1956
1914	Laurance I. Neale	Mar. 31, 1956
1922	Heath Steele	Feb. 21, 1956
1899	Archer E. Wheeler	Mar. 8, 1956

Proposed for Membership

— Metals Branch AIME —

Total AIME membership on Apr. 30, 1956 was 24,309; in addition 2,596 Student Associates were enrolled.

ADMISSIONS COMMITTEE

R. B. Caples, Chairman; F. A. Auer, Vice-Chairman; A. C. Brinker, R. H. Dickson, C. R. Dodson, R. B. Fulton, T. D. Jones, F. W. Hanson, Sidney Rolle, F. T. Sisco, O. B. J. Fraser, F. W. McQuiston, Jr., A. R. Lytle, L. P. Warriner.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

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Junior to Members

Cyril J. Osborn, Melbourne, Vic., Australia

Student to Junior

Carl J. Liswith, Richmond, Va.

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Medal for mining; R. W. French, chairman, Anthony F. Lucas Medal for petroleum; M. L. Haider, chairman, Charles F. Rand Medal for mining administration; C. Y. Garber, chairman, Robert H. Richards Award for mineral beneficiation; J. S. Marsh, chairman, Benjamin F. Fairless Award for iron and steel; C. M. Squarcy, chairman, J. E. Johnson Jr., Award for iron and steel (recipients under 40); J. C. Calhoun Jr., division chairman, Mineral Industry Education Award; K. L. Cook, division chairman, Jackling Award for mining, geology, or geophysics.

The following awards have also been authorized for best papers: Robert W. Hunt Medal, Mathewson Medal, Extractive Metallurgy Division Award, and the Rossiter W. Raymond Award.

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— Coming Events —

June 17-23, Fifth World Power Conference, Vienna, Austria.

June 17-22, ASTM, annual meeting, Hotel Chalfonte-Haddon Hall, Atlantic City.

June 32-July 6, International Machine Tool Exhibition, Olympia, London, England.

Aug. 6-8, SAE, West Coast meeting, Mark Hopkins Hotel, San Francisco.

Aug. 23-25, National Council of State Boards of Engineering Examiners, Hotel Statler, Los Angeles.

Sept. 9-12, AIChE, William Penn Hotel, Pittsburgh.

Sept. 10-14, New York University, second annual titanium lecture program designed for practicing engineers, College of Engineering, NYU, New York.

Sept. 16-22, ASTM, Pacific Coast meeting, Statler Hotel, Los Angeles.

Sept. 26-28, AIME, Rocky Mountain Minerals Conference, Salt Lake City.

Oct. 8-10, AIME, IMD Fall Meeting, Hotel Carter, Cleveland.

Oct. 8-12, ASM, national metal congress and exposition, Cleveland Public Auditorium, Cleveland.

Oct. 12, AIME, NOHC Eastern Local Section, annual meeting, Philadelphia.

Oct. 14-17, AIME, Petroleum Branch, Biltmore Hotel, Los Angeles.

Oct. 16-18, AIEE, conference on magnetism and magnetic materials, Hotel Statler, Boston.

Oct. 22-24, ASA, annual meeting, Hotel Roosevelt, New York.

Oct. 24-25, AIME-ASME, Joint Solid Fuels Conference, Sheraton-Park Hotel, Washington, D. C.

Oct. 28-Nov. 1, Electrochemical Soc., Statler Hotel, Cleveland.

Nov. 7, AIME, Pittsburgh Local Section, NOHC Pittsburgh Local Section, annual off-the-record meeting, William Penn Hotel, Pittsburgh.

Nov. 8-10, AIME, Mining Branch, Northeast Regional Meeting, Hotel Hershey, Hershey, Pa.

Dec. 5-7, AIME, Electric Furnace Steel Conference, Hotel Morrison, Chicago.

Dec. 9-12, AIChE, annual meeting, Statler Hotel, Boston.

Feb. 24-28, 1957, AIME Annual Meeting, Roosevelt and Jung Hotels, New Orleans.

Mar. 10-16, 1957, EJC Second Nuclear Engineering and Science Congress, Convention Hall, Philadelphia.

Mar. 25-29, 1957, ASM And Others, Tenth Western Metal Exposition and Congress, Pan-Pacific Auditorium and Ambassador, Los Angeles.

Apr. 8-10, 1957, AIME National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conferences, William Penn Hotel, Pittsburgh.

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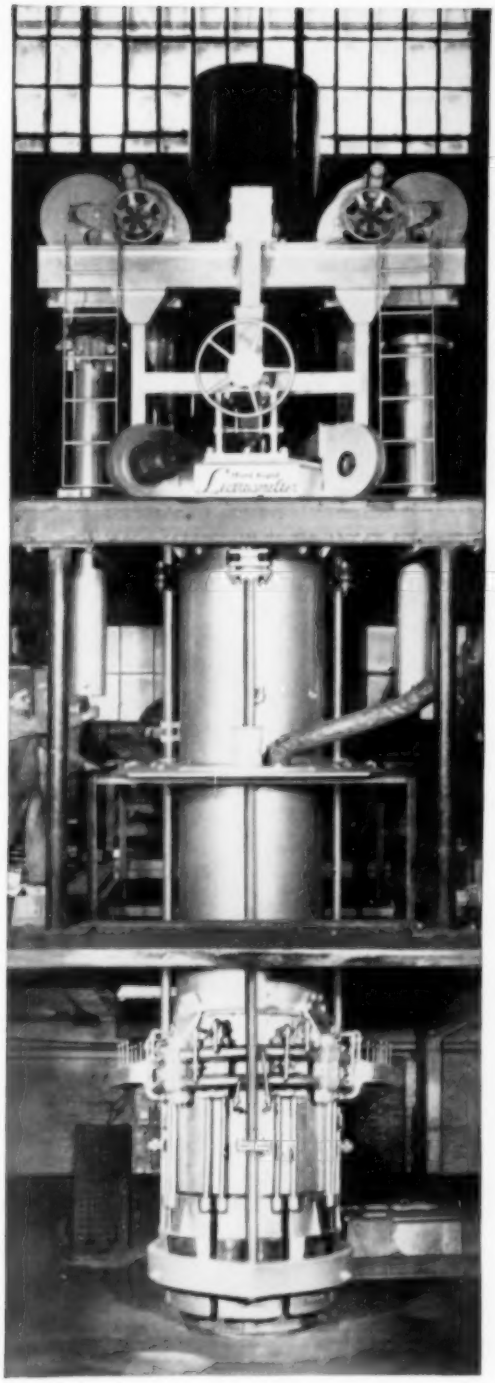

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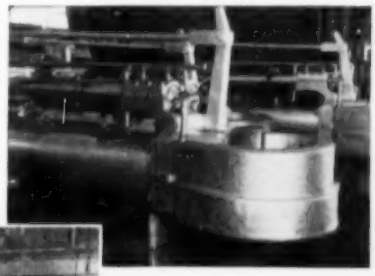

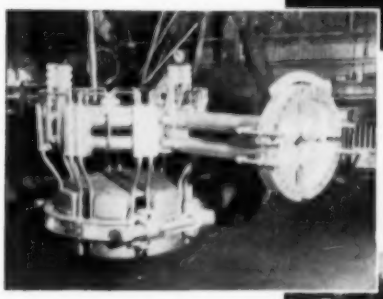

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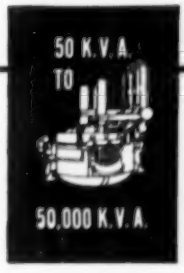

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